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# PEDESTRIAN MOBILITY IN DENVER: A MIXED METHODS APPROACH

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A Thesis

Presented to

The Faculty of Natural Sciences and Mathematics

University of Denver

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In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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by

Meghan Mooney

June 2015

Advisor: Dr. Andrew Goetz

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### **Abstract**

This research is rooted in the bigger issues of climate change, urban sustainability, and the drive to make Denver more pedestrian centered despite sprawled conditions. More specifically, this research is driven by (1) the need for a holistic, multi-dimensional, and mixed geographic perspective of pedestrian mobility, (2) the lack of qualitative data regarding pedestrian mobility and (3) a need for a better understanding of the feedback between physical and perceived space and how this influences walking behavior. Given these motivations, I deploy a multidimensional framework for assessing pedestrian mobility in Denver's Transit Oriented Development (TOD) sites, whereby there are two primary dimensions to pedestrian mobility—the spatial and the behavioral. In order to model and explore these dimensions, this research takes a mixed methods GIS approach to capture physical and perceived space, as well as actual walking behavior. To do so, 3D walk scores and walksheds were computed for TOD study sites, using conventional GIS methods, and were compared to more qualitative GIS sketch map and survey data collected on perceived space and walking behavior. The results of the mixed methods research confirm that the relationship between space and behavior is complex, whereby physical space influences perception and perception greatly influences walking behavior. Therefore, given these findings, planners need to focus efforts toward positively



influencing perceptions of pedestrian space in order to effectively encourage pedestrian mobility in Denver's auto-dominated landscape.

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## **Chapter One: Introduction**

Of all the components that make a city sustainable, walkability is perhaps the most important yet least understood. Commonly described as the relative ease to which the built environment facilitates pedestrian foot travel, walkability is largely a reaction against suburban sprawl. Suburban sprawl is a colloquial term that refers to the reorganization of the urban landscape from people toward automobiles. Smart Growth America defines sprawl based on four dimensions—“a population that is widely dispersed in low density development; rigidly separated homes, shops, and workplaces; a network of roads marked by huge blocks and poor access; and a lack of well-defined, thriving activity centers, such as downtowns and town centers” (Ewing, Pendall, and Chen, 2002, p. 3). In the United States, sprawl is the key driver behind a whole host of complex urban problems such as social, mental, and physical welfare, economic vitality, and environmental sustainability; and walkability offers a simple and practical solution to these urban ills (Speck 2012). Socially, pedestrian oriented cities offer a way for urban citizens to combat obesity, heart disease, and depression while obtaining their daily doses of exercise and interactions with nature. Economically, walkable cities allow citizens to spend less money on automotive transportation and invest more within the local economy while, at the same time, also attracting the wealthier creative class and stimulating development. Perhaps most importantly, walkability allows cities to obtain lower



emissions, lower pollutant levels, less habitat fragmentation, and an overall lower ecological footprint. Therefore, in order to make cities more socially, economically, and ecologically sustainable, walkability must play a keystone role in current and future urban policy, planning, and design.

Thankfully, the critical importance of walkability is something that people are beginning to recognize. Cities all across the United States are beginning to advocate for a shift in transportation mode from driving to walking. Despite its recent popularity, however, most people continue to drive. So one might ask: If people understand the importance of walking for transport, why don't they just give up driving all together? Well, unfortunately, the problem with this is not an issue of choice, but rather, an issue of the built environment space. Thanks to sprawl and auto-centric highway policies, American cities have become cities built for cars—not people. Unlike pedestrians, automobiles take up a considerable amount of room, stretching out the urban landscape at its seams, making walking both impractical and largely impossible. More often than not, people cannot walk even if they wanted to. So with the built environment designed for automobiles, trying to encourage and plan for walking is a difficult task—and the larger question becomes: *How do we encourage walking in spite of sprawled conditions?*

Planners and policy makers have been grappling with the question for decades, and many have emphasized focusing planning efforts on specific areas within a city, such as Transit Oriented Development (TOD) sites, downtowns, and neighborhood corridors (Schlossberg and Brown 2004; Agrawal, Schlossberg, and Irvine 2009; Speck 2012; Zook et al. 2012). Regardless of the specific focus areas, the approach to walkability has

largely been a single level analysis (varying from study to study on which is used). In fact, to my knowledge, few studies have looked at pedestrian mobility holistically across multiple dimensions (Boarnet 2011). This is surprising because, if walking is an issue of the built environment space, then we must understand it on a multi-dimensional level. Only once we fully understand pedestrian mobility across different spatial and non-spatial dimensions, can we effectively encourage walkability within our cities.

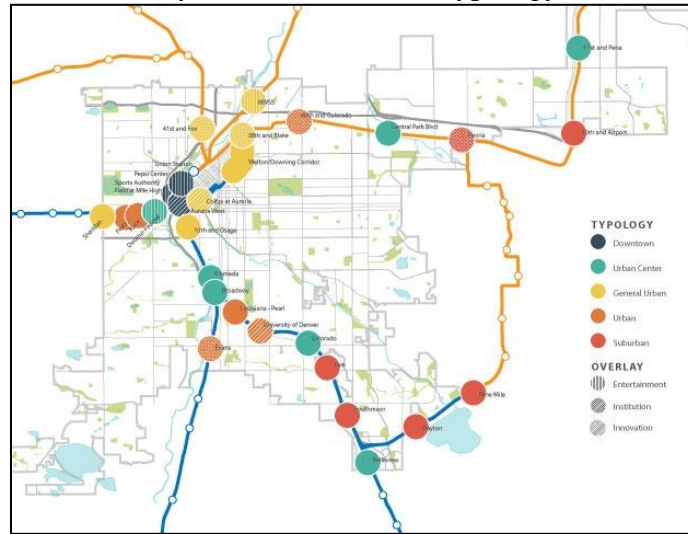
Currently, Denver, Colorado has been working toward making the city a walkable and transit community. The latest 2014 TOD Strategic Plan is perhaps the most obvious example of how Denver's planners and policy makers have been making impressive strides toward making Denver a more walkable and transit community (Denver 2014). Despite these latest developments, efforts have largely been unsuccessful city wide because the forces of sprawl greatly influence the overall effectiveness and connectivity of walking space across the city. Indeed, there is much more work to be done. Before we can truly make Denver more walkable, we must first understand the various spatial and behavioral dimensions of mobility. This research attempts to unlock some of these problems related to space and pedestrian mobility in order to progress sustainability and active transport. If we can understand how pedestrian mobility is influenced at different spatial and non-spatial dimensions, then we can try to find ways in which to encourage walking in a city that has been built for cars.

### **Transit Oriented Development and Pedestrian Mobility in Denver**

The best location for planning efforts is conditional to the city in question. Denver, Colorado, has a strong history of streetcar suburbs that have allowed for higher

density and a walkable landscape in much of the central areas of the city. But, like many of its fellow American cities, Denver experienced a considerable amount of suburban sprawl in the years after WWII. Today, Denver remains a low-density city with an even lower density metropolitan area, where the more walkable areas are reserved for the central, more affluent neighborhoods. So the problem remains, how can we make Denver a more walkable city for everyone despite sprawled conditions? For Denver, I believe the answer partially resides in the region's FasTracks program and Transit Oriented Development (TOD) zones. The Regional Transportation District's (RTD) FasTracks program is dedicated to connecting the larger metropolitan area with a light and commuter rail system in order to increase non-auto mobility and accessibility throughout the larger region (Ratner and Goetz 2013). Transit Oriented Development sites, or TODs, are defined by the half-mile buffer around transit stations (Schlossberg and Brown 2004). In Denver, these TODs are perhaps some of the best locations to focus planning efforts due to the public transit systems' ability to increase regional connectivity across sprawled environments, see Figure 1.

Figure 1: Denver Citywide TOD Station Typology



*Source: Denver 2014*

Currently, a good number of Denver's TODs are not walkable due to their proximity to interstate or other areal barriers (Denver 2014). However, making them walkable would increase accessibility of the areas within the city that could be accessed by foot, and ultimately, engendering seamless walkability. For these reasons, this research focuses its study sites on Denver's current RTD light rail TODs. In particular, four TOD sites were chosen—namely, Alameda, Louisiana Pearl, Union Station, and 27<sup>th</sup> and Welton. A further detailed description of these sites is highlighted in Chapter Four.

### **Theoretical Background**

Within the current geographic research on transportation and mobilities, there is an epistemological and methodological divide that has plagued advancement in research. Transport research in walkability has largely been a more objective and quantitative approach concerned with pedestrian connectivity and accessibility of the urban space. Conversely, mobility research on pedestrian mobility has been concerned largely with

individuals' subjective experiences of walking and has used more qualitative measurements. Though the two are often interpreted as binary approaches to studying pedestrian movement, transportation and mobility research are actually mutually informative, and together, they play a critical role in answering the question of how to make cities more walkable. In fact, synthesizing the physical space with individuals' experiences of walking would fully encapsulate and solidify the pedestrian experience in relation to the built environment; however, to my knowledge, no study has effectively done so. **Therefore, this research intends to utilize hybrid geographies and mixed methodologies in order to encapsulate this complex, multi-dimensional, human-environment interaction and progress walkability research and urban sustainability. In doing so, I will deploy a multidimensional framework for assessing pedestrian mobility in Denver's TODs. This multidimensional framework holds that there are two primary dimensions to pedestrian mobility: (1) the spatial, or walkability, dimension, and (2) the behavioral dimension.**

#### **Goals and Objectives:**

This research is rooted in the bigger issues of climate change, urban sustainability, and the drive to make Denver more pedestrian centered despite sprawled conditions and car-culture. More specifically, this research is driven by 1) the need for a holistic multi-dimensional and mixed geographic perspective, 2) the lack of qualitative data regarding pedestrian mobility and 3) a need for a better understanding of the feedback between physical and perceived space and how this influences walking behavior. Given these motives, four research questions are posed: **(1) How walkable is each TOD site? (2)**

**What is the relationship amongst perceived and physical walking spaces? (3) How does the spatial context affect walking behavior? (4) What needs to be done to facilitate more walking at these sites?** All four questions are investigated using a mixed methods spatial analysis approach.

## **Chapter Two: Literature Review**

This literature review navigates the pertinent bodies of literature related to this research, including common trends, successful applications, and gaps and limitations. The first section of the review starts with a general background on pedestrian mobility, including an account on historic trends in public perception, as well as the recent trends that have led to a shift in public perception toward accepting and demanding for pedestrian-oriented spaces. The second section of this review takes the reader into a more detailed literature-driven summary and assessment of walkability literatures, especially in regards to the three main measures of walkability commonly utilized by walkability researchers. Next, I open the doors to the more geographic literature on transportation and mobility, which I explain the current divide in human geography at large and how this is translated down to transport and mobility research. Subsequently, I detail the importance of hybrid geographies for transport-mobility research and highlight some formative examples of successful hybrids in transport-mobility research. Finally, I end with a discussion of the implications of the literature and the apparent need for a more geographic approach in walkability studies.

## **General Background on Pedestrian Mobility**

Pedestrian mobility involves the actual movement of people across space, their individual and collective behaviors, lived experiences, and perceptions of space that influence people's mode choice and actual behavior. Walkability, or the degree to which the built environment facilitates pedestrian foot travel, is one aspect influencing actual pedestrian movement. Within the mobility perspective, there has been a great deal of research pertaining to solutions to make our cities more walkable or pedestrian-oriented, including a popular book by Jeff Speck titled, *The Walkable City: How Downtown Can Save America One Step at A Time* (Speck 2012).

In terms of the most important conditions for walking within the literature, there are many differing approaches researchers make. Some argue that the physical space conditions, such as density, mixed land uses, and connective streets offer the most optimal conditions for walking (Cervero and Kockleman 1997; Frank et al. 2005), while others argue that the number or type of destinations (Lee and Moudon 2006; Millward, Spinny, and Scott 2013) or the total walking distance or time is the most critical conditions of walking (Lee and Moudon 2006; Agrawal, Schlossberg, and Irvine 2009, Millward, Spinny and Scott 2013). Yet still, there is a strong amount of literature that discusses the more qualitative aspects of space, such as the presence of other people, the amount of lighting, or the crime and traffic safety aspects as being the most fundamental conditions for walking (Foster, Giles-Corti, and Knuiman 2014). For instance, one especially famous researcher that has argued about the importance of other people for social policing and vibrancy of street life is Jane Jacobs, in her book titled, *The Death*



*and Life of Great American Cities* (Jacobs 1961). This stance on pedestrian mobility is quite different from those that take a more quantitative approach to measuring and predicting walkable urban space. Nonetheless, despite these differences in defining and measuring the necessary conditions for walking, most research agrees that, when compared to other modes, the urban space influences pedestrian mobility differently (Koohsari, Badland, Giles-Corti 2013). This is largely because pedestrians move at slower speeds and the movement takes place directly in urban space, or in other words, without a barrier between the pedestrian and the street. As a result, pedestrians are more vulnerable to the design and configuration of urban streets and pathways, and therefore, this vulnerability plays a direct role in one's decision to walk.

### **Historic Changes in Public Perception and Attitudes**

Public perceptions and attitudes of walking have changed over time. In the early 20<sup>th</sup> Century, people primarily walked, in addition to using the street cars; therefore, urban land was built around the need to move by foot, creating dense walkable neighborhoods and streetcar suburbs. It was not until the onset of the affordable automobile—especially after the Second World War—that Americans shifted away from using public transit and walking and moved toward a more auto-centric mobility. Indeed between the 1940's and early 2000's, Americans were auto-obsessed. Increasing numbers of people owned and drove a car. Much of urban and regional planning in the 1950s and 1960s was directly concerned with urban renewal type projects, which most often involved some combination of bulldozing existing neighborhoods throughout a city in order to build more highways, wider lanes, and bigger parking lots. As a result, the

American landscape had changed from dense walkable neighborhoods to a landscape of sprawled development that directly inhibits non-automotive mobility such as walking.

### **Recent Trends**

Somewhere in recent history, in the early 2000s, the American public perception and attitudes toward pedestrian mobility shifted once again—this time in favor of non-automotive mobility. The impetus for the shift involved a complex set of forces, both social and environmental, taking place at the exact same time (Gallagher 2013). On the one hand, the switch in perception is connected to the Green Movement, or sometimes referred to as the Sustainability Movement, which really took off in 2007. During this time, the American public became increasingly aware of complex environmental issues, particularly related to climate change, energy use, and oil consumption. As a result of this increase in public environmental education, many sought moving away from automotive lifestyles (Gallagher 2013).

At the same time, a complex set of social processes were beginning to take off. First, there is the change in demographics, whereby the population is becoming both older and younger, and more diverse (Gallagher 2013). For instance, members of the Baby Boomer generation are quickly becoming “Empty-Nesters” and thus they are increasingly reevaluating their large, isolating suburban homes (Speck 2012; Gallagher 2013). At the same time, as their children, the Millennials, are leaving their parent’s homes, they are not moving to suburbs, but rather, they are moving to cities. Indeed, roughly 77% of Millennials (those born between 1977 and 1995) move to urban areas after leaving home (Gallagher 2013). This trend is in line with what Fishman terms “The

5<sup>th</sup> Migration,” whereby, the most recent and ongoing urban migration pattern in the United States is a large scale movement from suburban fringes to urban centers—and the Millennials are no doubt the driving demographic force behind the widespread migration (Fishman 2005; Gallagher 2013). In fact, the year 2011 marked the first time in almost a century that the rate of suburban population growth did not outpace the rate of urban population growth (Gallagher 2013). Coupled with the transition to urban areas, Millennials have shown to have less desire to own or drive cars, and in turn, they are switching to alternative modes, such as some combination of walking, biking, and public transportation (Speck 2012; Gallagher 2013). Similar to this demographic change is the change in the economic markets and the American workforce, particularly related to what Richard Florida refers to as “The Creative Class,” in which increasing numbers of the American workforce are employed in the creation of new forms (i.e. art, music, advertising, science), and these members have particularly unique expectations of cities, including the desire to live in areas that are vibrant and walkable (Florida 2003). Subsequently, Florida argues that cities should market toward these individuals in order to grow economically. Finally, a third social factor contributing the social dimension of this change in public perception is directly related to public health and issues concerning both Adult and childhood obesity. The main argument here is that people are beginning to recognize the deteriorating effects of the automobile on public health.

As previously detailed, both of the environmental and social changes culminated in the change in public perception toward favoring active non-automotive types of mobility, such as walking. Though the change in public perception is still taking place, it

is very clear that walkability or desires to make cities more walkable has greatly impacted our urban and regional policy and planning, as well as individual's choices. Today, walkability is a *hot-topic*—one which is increasingly talked about in academia, engineering, policy and design, and even social media. The popularity of WalkScore, a web-based tool that measures how walkable a neighborhood is based on its proximity to destinations, and its integration into real estate markets is perhaps the best example of the increasing demand for walkable cities. People rely on this tool to choose places to live, while at the same time, communities are using it to their advantage to attract more economic growth (Speck 2012). Indeed, this has led to recent equity issues pertaining to walkable neighborhoods and access to destinations within walking distance. Part of the reason for these issues is that there is such a demand for living within the walkable neighborhoods, therefore, they are more economically competitive and, in many places, exclusive. Within Denver alone, the difference in real estate cost is 150 times greater in areas that are defined as “walkable urbanism” compared to areas defined as “drivable sub-urbanism” (Speck 2012). This difference alone highlights the recent increased popularity and demand for walkable neighborhoods caused by this shift in public perception toward a desire to live a non-automotive lifestyle.

### **Walkability Literatures**

Walkability refers to the degree in which the built environment facilitates pedestrian foot travel, and therefore, is a term associated with the spatial dimension of pedestrian mobility. This literature on walkability has its roots in sustainable planning movements of the 1990's such as New Urbanism and Smart Growth, and the walkability

movement has largely been a human-scaled reaction against sprawl that has dominated the US since WWII (Al-Hagla 2009; Speck 2012). The main argument here is that the size and the configuration of the sprawled built environment has spawned an overwhelming reliance on personal automobiles.

Within the walkability literature, there has been a plethora of articles studying the built environment correlates of walking behavior, including at least seven reviews (Ewing and Cervero 2001; Handy et al. 2002; Saelens, Sallis, and Frank 2003; Badland and Schofield 2005; Sallis et al. 2006; Saelens and Handy 2008; Koohsari, Badland, and Giles-Corti 2013) and one meta-review (Ewing and Cervero 2010). Two main branches—public health and urban transportation and design—have generated most of the walkability research. There is a vast number of different ways in which urban design and public health researchers have examined walkability. Despite this variability, there appear to be three main measures of the built environment in which researchers have examined walkability—(1) general walkability, or the 3Ds (Density, Diversity, and Design), (2) distance-oriented walkability, and (3) perceived walkability. Both general and distance-oriented approaches take an objective approach by examining components of physical space while perceived approaches examine individuals' subjective experiences, ideas, and conceptions of space. Simply put, objective measures assess factors of the built environment space that affect walking behavior whereas subjective measures evaluate individual perceptions of the built environment space that then affects their walking behavior. In addition to--or in conjunction with—these three different levels of analysis, a number of walkability studies assess attributes related to walking

behavior, including both actual walking behavior and the perceptual aspects that influence behavior, as well as walking demographics. Discussed in the next two subsections is the research pertaining to the three measurements of space as well as demographics and behavior.

### **Three Measures of Walkability**

#### *General Walkability—the 3Ds: Density, Diversity and Design*

General walkability measures characterize urban form by a set of computed indices based on the general layout of the built landscape (Bejleri et al. 2011). The most widely accepted measurement of general walkability for transportation relates to the 3Ds of the built environment—Density, Design and Diversity (Saelens et al. 2003). Urban planners, Cervero and Kockelman (1997), originally developed the 3Ds of walkability to represent the three main dimensions of the pedestrian environment that facilitates pedestrian mobility. Stemming from this framework, Frank et al. (2005) later adopted the 3D concept into an objective index for measuring walkability. Since its inception, the 3Ds have been popularized by New Urbanism (Handy et al. 2002) and are most often thought of as population density, street connectivity, and mixed land use diversity (Werner, Brown, and Gallimore 2010). To some, the 3Ds are thought to encompass the main workings of walkability: denser populations indicate less wasted space, making traveling by foot possible; connective street networks allow for quicker, more direct routes for pedestrian mobility; and mixed land uses allow for the integration of functional spaces such as retail, offices, and residential, allowing for the close proximity of origins and destinations (Cervero and Kockelman 1997; Frank et al. 2005). In support of these

assertions is an incredible amount of research and even a meta-analysis which compiled all walkability literature findings into one analysis of travel and the built environment and found that walking is most strongly related to measures of land use diversity (Diversity), intersection density (Design), and the number of destinations within walking distance (Density) (Ewing and Cervero 2010).

In essence, the 3Ds are the foundations of walkability whereby, without their collective existence, walking for transport would not take place. Moreover, general walkability has the ability to give a broad overview of the non-context specific walkability of a neighborhood and across the city. Third, general walkability measurements are good for ranking or scoring geographic areas in terms of walkability, and thus, make comparing areas and concentrating planning efforts easier.

Though the 3Ds are comprehensive in scope, it is still a vague categorization for assessing the spatial dimension of pedestrian mobility. Subsequently, the 3Ds have contributed to major discrepancies across studies, especially when researchers are defining walkability in different ways. For example, walking for exercise is not necessarily contingent on high intersection densities or mixture of land uses (Eriksson et al. 2012). On the other hand, when examining walking for transport, these design and diversity components have been proven to be of utmost importance (Ewing and Cervero 2010). Additionally, even within pedestrian transport research, the 3D framework is not an entirely inclusive index for walkability for specific social subgroups. For instance, research relating to children's travel to school has found that traffic and connectivity are the most important components to walkability while land use mix is considered

unimportant (Saelens and Handy 2008; Bejleri et al. 2011; Giles-Corti et al. 2011).

Another, problem of the 3Ds as an objective measure is that this framework does not entirely account for route- or destination- scenarios of walkability. Surely, one can argue that land use mix, population density, and street connectivity accounts for proximity and accessibility of destinations and origins (high population density, land use mix, and street connectivity entails more people living near destinations with direct routes) and this argument would be valid, but, only partially so. In reality, the 3D framework only indirectly relates to destinations and routes, but it does not tell the whole story.

Ultimately, the literature has shown that the 3D framework for walkability is too general an index for detailed analysis of proximity and accessibility because it leaves too much room for user-misinterpretation. Instead, the 3D framework should act as a bigger picture foundation from which researchers should conduct further detailed and case-specific analysis of other dimensions of space.

#### *Distance-Oriented Walkability*

The second type of walkability study, distance-oriented walkability, is concerned with origins and destinations of pedestrian mobility. Arguing that the conventional 3D dimensions of general walkability are inconclusive, Lee and Moudon (2006) present an alternative to walkability that is more origin and destination oriented, calling their framework the 3D's + R—Destinations, Distance, Density and Route. Under this notion, those that examine walkability in terms of origins and destinations are concerned with the accessibility of origins and destinations and the routes' connectivity (Hoehner et al. 2005; Lee and Moudon 2006; Agrawal, Schlossberg, and Irvin 2008; Chin et al. 2008; Bejleri et



al. 2011; Gallimore, Brown, and Werner 2011; Tal and Handy 2012; Zook, Glanz, and Zimring 2012; Guo and Loo 2013; Koh and Wong 2013; Millward, Spinney, and Scott 2013). Thus, pedestrian accessibility is a keystone characteristic of walkability that is defined as the function of proximity to desired destinations or land use mix and connectivity of mobility networks (Tal and Handy 2012). All of the studies that employ origin-destination frameworks consistently find that distance, or proximity, is the number one correlate of the built environment that determines walkability (Handy et al. 2002; Humpel, Owen, and Leslie 2002; Lee and Moudon 2006; Saelens and Handy 2008).

Compared to general 3D frameworks, most origin-destination approaches to walkability are site specific, meaning that they measure walkability from a given point, or node, rather than examining walkability of the overall neighborhood or study site. Common measures of origin-destination walkability include the straight-line distance buffer around a given node (Cervero and Kockelman 1997; Frank et al. 2005; Lee and Moudon 2006), roadway network distance (Dill 2004; Frank et al. 2005; Lee and Moudon 2006), and pedestrian sheds (also called pedsheds or walksheds) (Chin et al. 2008; Tal and Handy 2008; Giles-Corti et al. 2011). The pedestrian shed is a relatively new concept that is increasingly being incorporated in walkability research within the past couple of years, specifically relating to children's travel to school (Bejleri et al. 2011; Giles-Corti et al. 2011) and transit oriented development (TOD) (Agrawal, Schlossberg, and Irvin 2008; Ewing and Bartholomew 2013). Pedestrian networks or pedsheds are the areas that can be reached by walking along formal (streets) or informal paths (footpaths, parks, bridges, etc.) within a specified straight-line walkable distance of an origin (Dill

2004). This consensus of the walkable distance ranges from  $\frac{1}{4}$  to  $\frac{1}{2}$  mile (Cervero and Kockelman 1997; Frank 2005; Bejleri et al. 2011), but can vary depending on the destination. In fact some studies have found that people are willing to walk considerably further (more than 1 mile) to access high speed transit networks than to other destinations and slower transit systems (Agrawal, Schlossberg, and Irvin 2008). Measuring walkability in terms of pedestrian sheds is origin specific, meaning, it requires researchers to select specific nodes from which to analyze the pedestrian 'service area' (Tal. and Handy 2011). Pedsheds are particularly useful for addressing walkability in a way that transcends traditional measurements, such as the straight line and network distances, because pedsheds take into account specific pedestrian-specific elements of the built landscape, particularly, barriers, such as highways and fences that may impede pedestrian mobility, as well as facilitators, such as back-entrances, pedestrian-only bridges, and parks, that may enhance pedestrian permeability (Chin et al. 2008; Bejleri et al. 2011). Pedsheds are useful for examining the pedestrian mobility complexities in terms of accessibility, proximity, and connectivity. More specifically, pedsheds highlight the fact that when people walk toward a specific destination, they will consistently seek out the shortest path, whether formal or informal (Agrawal, Schlossberg, and Irvin 2008; Bejleri et al. 2011). This choice component is a factor that is highly emphasized in origin-destination studies, but only indirectly accounted for in general walkability studies.

### *Perceived Walkability*

Subjective measures of the built environment are concerned primarily with the pedestrian experience walking through the urban environment (Leslie et al. 2005; Leslie

et al. 2007, Kelly et al. 2011). Most studies that perform subjective measurements of the built environment in relation to pedestrian mobility do so through recall questionnaires and surveys like the International Physical Activity Questionnaire (IPAQ) (Frank et al 2005; Hoehner et al. 2005; Cerin et al. 2006; Eriksson et al. 2012; Millward, Spinney, and Scott 2013). The IPAQ questionnaire measures the amount of past walking activity of volunteer respondents as it relates to public health, thus, it is not the best tool for looking at pedestrian mobility from a transport and geographic perspective. Moreover, like the IPAQ, most of the past subjective questionnaires ask vague questions about participants ‘neighborhoods’—a highly ambiguous term conceptualized and defined differently from person to person—leaving room for discrepancies between responses that are hard to evaluate. A noteworthy study performed by Agrawal, Schlossberg, and Irvin (2009) examined pedestrian route choice near transit stations not by asking participants vague questions about their “neighborhoods” as most of the literature has done in the past, but rather, by asking them to trace on a map the path that they had walked and the different routes and intersections (if any) which they intentionally avoided (Agrawal, Schlossberg, and Irvin 2008). This study is groundbreaking in that it was one of the first to look at pedestrian choice in an empirical way. Moreover, this interactive mapping methodology helped to avoid survey question ambiguity and engendered verifiable perspectives of neighborhood walkability that could be related to objectively measured space such as route characteristics. Incidentally, if researchers want to better understand the individual subjectivity of pedestrian mobility in relation to the physical environment, they must design their methods to be as empirical as possible. It is

important to note that understanding all of the components that go into pedestrian subjectivity is a complex task that is never entirely an absolute representation of perspectives across people in different geographic areas and of different socioeconomic backgrounds. Nonetheless, what makes subjective walkability studies so powerful is their ability to do something that objective studies cannot, namely, they can provide a comprehensive view of the pedestrian perspective based on their psychosocial interactions with the built environment.

To my knowledge, other than the work from Agrawal, Schlossberg and Irvin (2009), there has been a gap in the perceived walkability literatures, particularly in the interaction of perceived space with other aspects of space, such as physical space. Additionally, instead of contextualizing perceptions into space, most perceived walkability research has focused primarily on obtaining data related to vague attributes of space that influence perceptions. In doing so, the current research on perceived walkability is neglecting the fact that perceived space, like physical space, can be visualized and assessed as a series of images. Visualizing perceived space allows researchers to understand not only how and why people feel and respond to their urban environments the way that they do, but also, it allows them to map and situate the perceptions amongst actual space, analyzing the complex relationship between people and their environments. Perhaps the best-known work related to visualizing perceived space was performed by Kevin Lynch in his seminal piece, *The Image of the City* (1960). In this work, Kevin Lynch took a humanistic approach to understanding how people conceptualize and perceive their urban environments. He collected individual's hand-

drawn mental map images of their cities and found that people perceive urban environments as a built image made up of five key elements of the built environment: paths, edges, districts, nodes, and landmarks (Lynch, 1960). Though to my knowledge, little work in the perceived walkability literature has used a similar approach to understanding the pedestrian environment, Lynch's methods hold a tremendous amount of merit today with understanding perceived space and spatial walking behavior. For instance, Lynch's five elements of mental map images could be used as a means to prompt sketch mapping exercises. Indeed, Agrawal, Schlossberg, and Irvine's (2009) work using sketch mapping could be furthered by analyzing the collective sketches of individuals as one public image of perceived space or actual walking behavior, looking for common key elements, such as origins or destinations (landmarks), walking routes (paths), common path intersections (nodes), areas perceived as safe for walking (districts), or those perceived as unsafe for walking (edges). Examining sketch maps in such a manner could equip planners with the toolset needed to better understand and collect data related to pedestrian mobility.

### **Demographics and Behavior**

The pedestrian research pertaining to demographics and behavior explores the demographic makeup of walking behavior in order to understand larger questions of *who*, *where*, and *why*. For example, the literature relating to behavior and demographics looks at who walks or does not walk, where people walk or do not walk, and why people walk or do not walk. With these questions in mind, there is a vast amount of different angles

taken by researchers to assess transport and pedestrian behavior. Discussed below are some of specific demographic influences of behavior from the walkability literatures.

For demographics, the research has consistently shown that there is a pretty distinct separation between certain demographic groups in terms of actual walking behavior, whereby those that exhibit little to no walking activity include non-Hispanic Blacks, Hispanics, Asians, elderly adults, children under the age of 16 living in more suburban or rural settings, and those living in high poverty areas (Gebel, Bauman, and Owen 2009; Forsyth et al. 2009; Freeman 2011; Boschmann and Brady 2013).

Conversely, the demographics of people with higher reports of walking activity include non-Hispanic Caucasians, those with at least some college degree, those in very good health, those who participate in any physical activity, and those living in higher income areas (Freeman 2011). In general, individuals that walk for transport live within higher density communities, regardless of their socio-economic background (Frank et al. 2008).

This generalization is representative of areas that are more socially and economically heterogeneous and it falls short when considering the extremes—both advantaged and disadvantaged neighborhoods. Despite density, advantaged neighborhoods, which have high proportions of high income households, are more walkable due to more investment in pedestrian infrastructure which then causes higher property values, ultimately leading to the concentration and social exclusion of pedestrian infrastructure (Cortright 2009). At the same time, individuals belonging to these higher income areas report more favorable walking conditions, including perceptions of safety from crime (Sallis et al. 2011). On the other hand, disadvantaged neighborhoods, which have high proportions of poverty, do

not have much investment in pedestrian infrastructure, and thus, have less walking activity, despite density (Hearst et al. 2013). Interestingly, some research has shown that disadvantaged neighborhoods that have good built environment attributes for walking (i.e. high densities, mixed use development, and high street connectivity), do not experience much walking due to their high degree of social and aesthetic qualities, such as real or perceived crime, that may inhibit pedestrian activity (Freeman 2011; Foster, Giles-Corti, and Knuiman 2014). Along a similar thread is a large number of the urban planning literatures that have examined walking perceptions in terms of perceptions of design and walking environment attractiveness (Agrawal, Schlossberg, and Irvine 2009; Boarnet et al. 2011; Adkins et al. 2012), however, most recently, scholars have begun to examine other factors, such as perceptions of fear or crime, in regards to walking behavior (Bracy et al. 2014). The relationship between perceptions and behavior is complex. Gabel, Bauman, and Owen (2009) found that adults with lower educational attainment and lower incomes, who were overweight, or who were less physically active for transportation purposes, were more likely to misperceive their high walkable neighborhoods as low walkable. These findings are indicative of the relationship between space, demographics and behavior. Who you are and where you live will likely shape your walking experience and behavior in one way or another. At the same time, these demographic dimensions of pedestrian mobility are intrinsically related to the spatial dimension due to social exclusion and other human geography distributions, such as concentrated areas of both pedestrian infrastructure and certain demographic groups.

Though there has been a considerable amount of progress in understanding walking behavior as it relates to differing socio-economic demographic groups, there is a good deal of room for advancement, particularly in regards to urban space. In other words, there could be better geographic understandings for how behavior and demographics are distributed throughout geographic space. This is a problem because the walkability literature provides statistical summaries of data collected from surveys, which assess the spatial demographic differences in walking behavior, however, there is no real map visualization for the distribution of such phenomenon.

### **Transportation and Mobilities**

Though most walkability research has been non-geographic, geography plays an intrinsic role in understanding the relationship between physical and perceived space. Two facets of contemporary geography are concerned with movement: traditional transport geography and mobilities (Shaw and Hesse 2010). Although they are both interested in movement, the literature often refers to these two areas of geographic research as two separate divisions reflective of the spatial-analytic and critical paradigms of human geography (Goetz, Vowles, and Tierney 2009). This geography binary in transport and mobilities mirrors the differences in objective and subjective measures of the walkability literature. Discussed in this section is this transport-mobility binary in general and how it relates to pedestrian mobility at large.

Most closely related to objective walkability studies is the traditional transportation geography. Transportation research is most often associated with the positivist philosophies, where objectivity and universality are among its main theoretical



holdings (Goetz, Vowles, and Tierney 2009; Shaw and Hesse 2010). Under this perspective, human movement operates under a sort of rational economic purpose, like moving machines and infrastructures, constantly seeking to maximize efficiency from Point A to Point B (Cresswell 2010; Shaw and Hesse 2010). Indeed, transport geography has had a long tradition in quantitative, analytical, and model building methodologies (Goetz, Vowless, and Tierney 2009; Cresswell 2010; Shaw and Hesse 2010; Merriman 2013). Specifically, there has been a large emphasis on spatial interaction and network analysis amongst transport research (Goetz, Vowles, and Tierney 2009). Spatial interaction and network analysis research is rooted in Ullman's work on site and situation, which utilizes locational theory and understandings of systems connectivity (Shaw and Hesse 2010). Furthermore, scope of transport methodologies aims to understand transportation infrastructure development and accessibility. Though this perspective of movement holds significant practical merit, this rational sort of understanding of movement has been the most heavily criticized aspect of transport geography and its alleged positivist approach because it falls short of explaining the dimension of the individual subjective experience.

Most closely related to the subjective walkability research in geography is mobilities. Mobility studies are a more critical, humanistic, and postmodern approach to movement that arose in reaction to the positivist nature of traditional transport geography (Cresswell 2010). This 'new' mobilities paradigm operates under the notion that humans are complex creatures. We have feelings, emotions, values, fears, hopes, and desires. We are also all different, with diverse socio-economic backgrounds and physical capabilities.

Indeed, for mobility researchers, the particular individual subjective experiences dictate movement across space, infusing it with meaning. To capture the subjective experience, mobility research has embraced more qualitative methods, heavily criticizing quantitative approaches as inhuman (Cresswell 2010; Merriman 2013). These qualitative methodologies deploy imaginative, participatory, performative and ethnographic techniques in their analysis of mobility (Cresswell 2010; D'Andrea, Ciolfi, and Gray 2011; Merriman 2013). Shaw and Hesse (2010) explain that this new mobilities paradigm fills a research gap in traditional transport geography because it “elucidates the framework conditions underpinning the generation of movement, the experience of movement and the implications thereof, and the wider impact of movement across a whole range of socio-cultural, economic, and political milieu” (Shaw and Hesse 2010, 306).

### **Hybrid Geographies of Walkability and Pedestrian Mobility**

At large, transportation and mobility geographies have been performing research independently. Recently, many scholars have called for a better synthesis and hybridization of transport and mobility geographies in order to generate a more holistic understanding of movement across space and place (Shaw and Hesse 2010; Sui and DeLyser 2012). Along a similar thread of advocating hybridity, Jones and Evans (2012) bring up the importance of epistemology and methodology in terms of synthesis, noting that “differing scales perhaps require different ways of thinking about these issues and definitely require different research methods to explore them,” (94).

Hybrid approaches of transport-mobility geography could come in all different shapes and forms; however, one universal aspect is their use of mixed methods to assess different dimensions of a phenomenon. By definition, mixed methods research “weaves together diverse research techniques to fill gaps, add context, envision multiple truths, play different sources of data off of each other, and provide a sense of both the general and the particular,” (Cope and Elwood, 2008, p. 5). In other words, mixed methods approaches integrate multiple forms of knowledge and findings from various techniques, both quantitative and qualitative, in order to inform a more robust understanding of complex processes and phenomenon (Cope and Elwood, 2008). Looking at multiple levels of analysis, as opposed to just one, can help walkability researchers to understand how the spatial context affects human behavior (Zolnik 2009). Moreover, different components of space play different roles depending on the angle of analysis, but overall, each spatial aspect of walkability is connected in its geography and mutually informs one another. Ultimately, individuals’ mobility experiences are contingent on the existence of particular transport structures; therefore, a complete analysis of mobility must incorporate traditional transportation understandings of connectivity and accessibility. In terms of pedestrian mobility, this means measuring the factors of space at different dimensions in order to lay the groundwork for how pedestrian mobility is preferenced and constrained throughout space.

The current literature on mobilities has been able to fill a research gap relating to the human experiences of mobility, however, effective connections with objective transportation geography have not been solidified. Even though there has been some

fantastic pioneering work in relation to hybrid geographies, especially in terms of Qualitative GIS (e.g. Agrawal, Schlossberg, and Irvin 2008; Cope and Ellwood 2009; Jones and Evans 2012; Boschmann and Cubbon 2014), I would argue that new research be taken the next step further, incorporating the qualitative with the quantitative, and the objective transport approaches with the subjective mobilities approach. For instance, Agrawal, Schlossberg, and Irvin's (2008) work on pedestrian route choice could be furthered by incorporating the results in a QGIS and then comparing the subjective choices with more objective data like street connectivity, population density, or mixed land uses. Doing so would bridge the epistemological-methodological divide between transport and mobility research, shedding light on the larger connections of how space actually shapes perceptions and behaviors. Moreover, hybrid geographies that make these cross scalar connections could aid in better policy making regarding non-carbon transportation strategies and design (Jones and Evans 2012; Sui and DeLyser 2012). In turn, it would enable a more holistic and complete story of the human-environment interactions of people moving across their built landscapes.

### **Implications of the Literature and the Need for a Holistic Geographic Approach**

In effort to provide a universal understanding of the multiple dimensions involved in this complex human-environment interaction, I propose a more geographic and multi-dimensional understanding of pedestrian mobility across multiple dimensions that stems from the aspects that have been proven to work in the existing literature and discussed throughout the review. Essentially, there are two main dimensions of pedestrian mobility—the spatial and the behavioral. The first component that affects pedestrian

mobility is the spatial dimension and essentially refers to the walkability of urban space, or the degree to which the urban landscape facilitates pedestrian movement. Because there are multiple dimensions of geographic space, the spatial dimension of pedestrian mobility must contain analyses of the multiple dimensions that make up geographic space. Accordingly, the holistic model organizes the spatial context of pedestrian mobility into two different types of geographic space—physical and perceived space. Based on the literature, the three measurements of walkability—general, distance-oriented, and perceived—are used as measurements of the spatial context component. The two different types of space can categorize these measures of walkability. The general and distance-oriented measures are defined as measures of physical space because they are concerned with aspects of objective and measureable space. On the other hand, the perceived measure of walkability is given its own spatial dimension (perceived space) due to its concern with non-literal and subjective feelings and attitudes toward objective space. Even though both walkability measures of physical space are measurements of objective space, they measure different aspects of objective space. In particular, general walkability is a measurement concerned with the necessary foundations of walkability (i.e. street connectivity, land use mix, and population density) that mostly must be present amongst the physical urban landscape before pedestrian movement would take place, whereas the distance-oriented measurement of walkability is concerned with the more accessibility and proximity dimensions central to origin-destination walkability. On the other hand, the perceived measure of perceived walkability is concerned with the subjective mobility experiences and cognitive

perceptions that individuals attribute to particular spaces. Though there are differences in space and spatial measurements, both perceived and physical space are connected by geographic location and together make up the spatial context in which human mobility behavior occurs.

The second dimension of pedestrian mobility is behavior. Individual and collective behaviors are a complex set of actions that are influenced greatly by three primary forces—the spatial context (both physical and perceived), socio-economic demographics (e.g. age differences in mobility behavior), and time considerations. The walkability of a particular place is important, however, it is not the only factor that influences pedestrian mobility. As the literature has shown, individuals react to space differently based on who they are and their individual needs and circumstances within time-space constraints. Only when both space and behavior are effectively considered do we begin to understand the complexities of pedestrian mobility. Therefore, by using this conceptual model as the framework, this research takes a hybrid transport-mobility geographic approach to walkability that effectively synthesizes the spatial and behavioral aspects of walking in order to provide a more holistic representation of pedestrian mobility in Denver's TODs.

### **Chapter Three: TOD Study Sites**

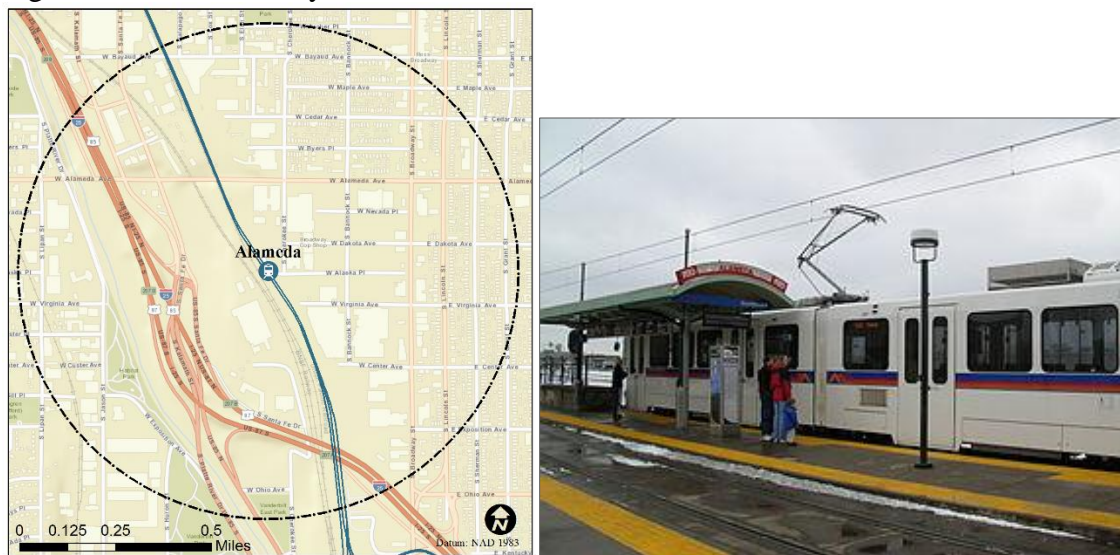
Instead of examining all current TOD areas, this research uses four study sites largely due to limited resources. These four study sites were chosen based on their official 2014 typology, as defined by the City and County of Denver, ensuring a mixed representation of typologies for chosen study sites, excluding the suburban typology. As defined in Denver's 2014 Transit Oriented Development Strategic Plan, there are five TOD typologies—namely, downtown, urban center, general urban, urban, and suburban—categorized based on common characteristics found within the TOD area (Denver 2014). The reason for choosing the study sites based on TOD typology is twofold. First, looking at different typologies aids in a better understanding of TOD pedestrian dynamics across a diverse set of built environments. Second, the city of Denver uses these typologies to set goals and plans for future development; therefore, the results of this study would be most informative if organized along the same typological framework. The four study sites chosen for analysis are Alameda, Louisiana Pearl, Union Station, and 27<sup>th</sup> and Welton. Detailed in this section is a bit of background information on each site designed to provide the essential geographic context for each site.

#### **Alameda**

Alameda Station is situated east of Santa Fe and west of Broadway at Alameda Avenue, servicing the Baker Neighborhood. The central parts of Baker are indicative of

the old street car suburbs, however, near the Alameda light rail station, the landscape is much more auto-oriented. In fact, the Alameda light rail station is sandwiched behind old big-box retail and huge swaths of underused parking lots on one side and industrial rail yards and distant highways on the other side. According to Denver's 2014 TOD plan, Alameda Station is considered an Urban Center type, whereby main characteristics include mixed use development, high density, grid and alley block pattern, high pedestrian activity, and multi-modal activity (Denver 2014). Immediately surrounding the station, however, the Urban Center typology characteristics are almost non-existent. Nonetheless, Alameda is undergoing major transitions (and major construction) from an isolated station separated by train tracks and industrial regions of Denver to a more pedestrian-oriented activity center.

Figure 2: Alameda Study Site

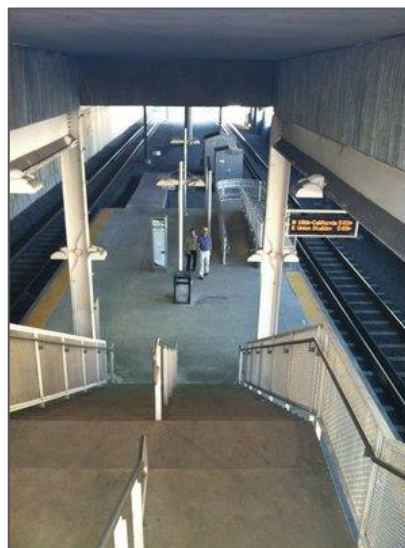
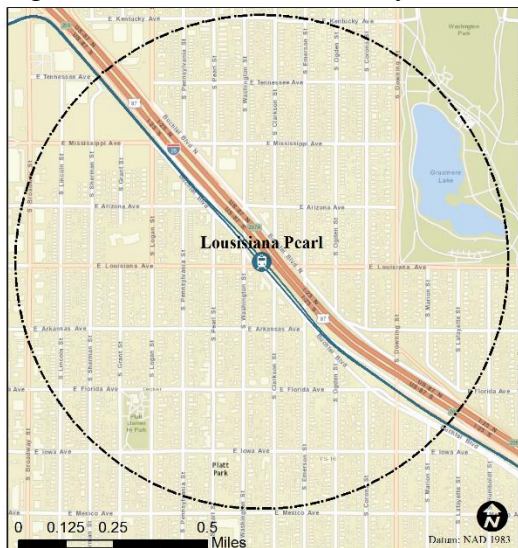




## Louisiana Pearl

Louisiana Pearl light rail station is situated along the interstate (I-25) at Louisiana Avenue and Buchtel Boulevard South. The TOD area extends on either side of I-25 from the northern boundary of Mississippi Avenue down to its southern boundary at Florida Avenue. Based on its TOD, the Louisiana Pearl Station is designed to serve the immediate neighborhoods of Platt Park, West Washington Park, and Washington Park. To many Denver Residents, Louisiana Pearl is an ideal neighborhood to live in because it offers the walkable neighborhood that many desire. Indeed, this neighborhood integrates the old and charming medium density residential neighborhoods, with an abundance of green space, convenient corner neighborhood stores, and access to light rail transit. Louisiana Pearl is considered an urban station type due to its grid and alley block pattern, predominantly single family residential, main streets, corner stores, and multi-modal activity.

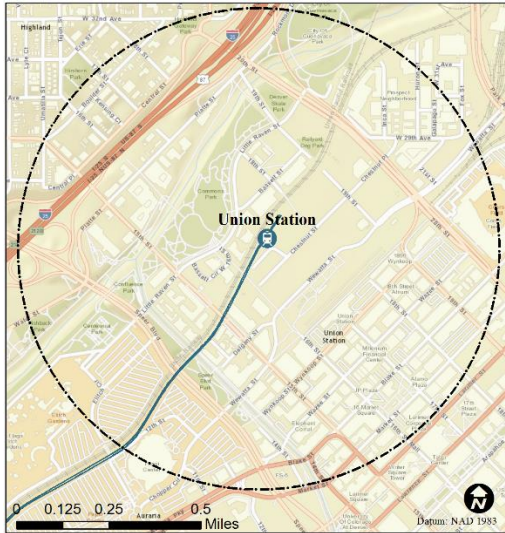
Figure 3: Louisiana Pearl Study Site



## **Union Station**

The Union Station light rail station, located in the heart of Lower Downtown (LoDo), is a part of the larger Denver Union Station multimodal transportation hub. This Union Station multimodal hub is a quarter-mile long complex that is planned to house many mobility options, including light rail, as well as other modes such as commuter rail, bus service, the free 16<sup>th</sup> Street Mall shuttle, and alternative modes like biking and walking. This complex just recently underwent construction in early 2014, and because of this, many surrounding regions are currently still undergoing construction at this time. The Union Station light rail station is located at the very back end of this complex situated northwest along the rail yard and furthest away from the downtown, closer to the interstate. According to the 2014 TOD plan, Union Station is a downtown station type, characterized by its mixed use, highest density, tallest buildings, high pedestrian activity, transit hub, and historic areas. All in all, Union Station area has a predominately pedestrian-oriented design, however, much of the region is undergoing major transitions and renovations.

Figure 4: Union Station Study Site



## 27<sup>th</sup> and Welton

Located in the historic Five Points neighborhood, the 27<sup>th</sup> and Welton Station is situated at the cross-streets of 27<sup>th</sup> Street and Welton Street, located along the Welton Corridor. Five points historically was an old street-car suburb that has seen a number of different demographic transitions in its time. In recent history, Five Points has been a predominately African American neighborhood, however, most recently, it has been the target of gentrification. For better or for worse, much of Five Points remains an area of slow transition today.

According to the 2014 TOD plan, 27<sup>th</sup> and Welton is a General Urban type characterized by multi-family residential, grid and alley block pattern, main streets, corner stores, and multi- modal. Unlike all the other stations, 27<sup>th</sup> and Welton station is reminiscent of an old street-car or trolley because the tracks are given their own lane on the road, they are subject to traffic lights and signs, and riders can essentially just walk down the sidewalk and hop on the train. In other words, there is no real clear distinction

to where the regular street side walk ends and the station begins. Additionally, much of the neighborhood is still reminiscent of the old street-car suburbs, whereby clustered around Welton are a number of shops and business type buildings, but unfortunately, many of them remain vacant.

Figure 5: 27<sup>th</sup> and Welton Study Site



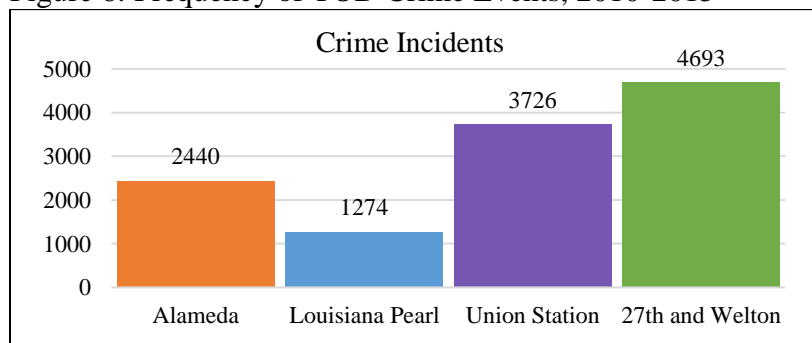
### Walkability Statistics of Study Sites

Because this research is interested in the relationships between perceptions, space, and behavior, there are a few critical statistics related to the demographic and geographic distributions of these sites that will be important to understand while reading this thesis. In particular, the amount of crime incidence and traffic accidents involving pedestrians and bicycles, the median household income, and the median home value of the study TOD area are all important statistics of these neighborhoods that related directly to relationships between behavior, perception, and space.

## Crime Events

Crime can have a significant impact on feelings of safety, and subsequently, individuals' mode choice. Because of this important link between crime and mobility, particularly pedestrian mobility, crime event data were collected for each TOD site in order to provide a better understanding of the safety dimensions of walkability in these areas. Figure 6 below depicts the number of crime incidents within each TOD area. Additionally, a hotspot map of the spatial distribution and density of crime is detailed in Appendix A. These data were collected from Denver's Open Data Catalog and they include events ranging from January 2010 to April 30<sup>th</sup>, 2015. As depicted in the crime frequency table, 27<sup>th</sup> and Welton has the largest frequency of crime events, however, both 27<sup>th</sup> and Welton and Union Station have a significantly larger number of crime incidences taking place within the surrounding TOD when compared to both Alameda and Louisiana Pearl. Alameda station has a smaller number of incidences compared to Union Station and 27<sup>th</sup> and Welton, however, it too has significantly more incidences—about 2,000 more—than the neighboring TOD neighborhood.

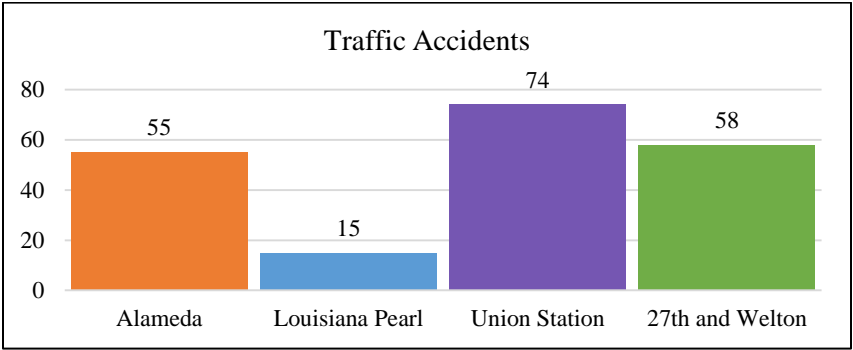
Figure 6: Frequency of TOD Crime Events, 2010-2015



## **Traffic Accidents**

Similar to the effects of crime on mobility, traffic accidents, especially those involving pedestrians or bicycles, can have a significant impact on pedestrian's safety, and therefore, can greatly influence one's mode choice. Due to this important link, traffic accident data were collected for each TOD site in order to provide a better understanding of the safety dimensions of walkability in these areas. Figure 7 below depicts the number of traffic accidents involving pedestrians or bicycles within each TOD area. Additionally, Appendix A contains a hotspot map of the spatial distribution of traffic accidents within each TOD site. These data were collected from Denver's Open Data Catalog and they include events ranging from January 2010 to April 30<sup>th</sup>, 2015. Interestingly, this table assumes a similar trend across all four stations as the crime events frequency table in Figure 7. The only exception between the two tables is that for traffic accidents, Union Station has a larger number of occurrences. Both 27<sup>th</sup> and Welton and Alameda have significantly fewer accidents than Union Station, however they both still have a greater number of accidents than Louisiana Pearl. Interestingly, Louisiana Pearl is divided by an interstate that literally cuts the TOD area into equal halves, and yet, despite its geography, this surrounding TOD neighborhood manages to have the lowest number of traffic accidents compared to all other study sites.

Figure 7: Frequency of TOD Traffic Accidents Involving Pedestrians or Cyclists, 2010 to 2015



**Median House Values**

Median house values do not necessarily have a direct link to pedestrian mobility, however, they are nonetheless a significant measure to consider how walkable a neighborhood is. In fact, by understanding the neighborhood’s median house values, researchers can have a better idea of the surrounding area’s maintenance or relative upkeep, safety or police presence, destinations or businesses, or accessibility functions like access to both parks and trails as well as public transportation. Due to these linkages between house values and other walkability aspects, the median house value for the surrounding TOD area was calculated and compared to Denver’s median house value as a z-score deviation from the city’s median value. The statistics on median house values were taken from the 2006-2010 American Community Survey for Denver Block Groups, and for each TOD site, all intersecting block groups were used to determine the median house value for the TOD area. As Table 1 highlights, none of the TOD areas are statistically different from the Denver median house value (\$266,305). In fact, all TOD sites have house values that are larger than the city median house value, however, these

differences are not too extreme since all four sites' median values are within one standard deviation from the city's median value.

Table 1: Median House Values, 2006-2010

Station	Median House Value	Z-Score
Alameda	\$300,857	0.23
Louisiana	\$386,282	0.78
Union	\$383,745	0.77
Welton	\$284,691	0.12
<i>Median values and deviations are based of ACS 2006-2010 for Denver block group median house values which has a <math>\mu</math>=\$266,305 and <math>\sigma</math>=\$152,975</i>		

### Household Income

Similar to the measure for median house values, percent household income of an area can tell you a lot about the type of people that live within the urban neighborhood as well as the type of activities that take place across space. Thus, due to these connections, household income for the TOD area was calculated based on the percentage of individuals belonging to low, moderate, and high income brackets. Table 2 below details the low, moderate, and high household income proportions for each TOD area compared to the Denver household income. For each income group (low, medium, and high) the TOD proportions were calculated based off of all intersecting block groups and then was compared as deviations from Denver income proportion for each respective income group. All data came from the 2010 American Community Survey for Denver. In Table 2, all positive or negative signs indicated next to the proportion values refer to those proportion values that are statistically different from Denver's proportion. Interestingly, Union Station was the only station that did not differ from the city's proportions for all three groups. As for the other three stations, there were significant proportion differences



in at least two groups. For instance, both Alameda and Louisiana Pearl differed from Denver's proportions of high and low income groups. Alameda had significantly higher proportions of individuals belonging to low income groups and lower proportions in high income groups. In contrast, Louisiana Pearl had lower proportions of low income and higher proportions of high income. As for 27<sup>th</sup> and Welton, there are fewer individuals belonging to the middle income bracket and more individuals within the low income bracket.

Table 2: Household Income Proportions, 2010

	<b>Low Income (10-50k)</b>	<b>Moderate Income (50-90k)</b>	<b>High Income (90k+)</b>
	<i>Proportion</i>	<i>Proportion</i>	<i>Proportion</i>
<b>Alameda</b>	0.47 (+)	0.31	0.21 (-)
<b>Louisiana Pearl</b>	0.23 (-)	0.34	0.44 (+)
<b>Union Station</b>	0.32	0.42	0.26
<b>27th and Welton</b>	0.45 (+)	0.19 (-)	0.36
<b>Denver</b>	0.33	0.34	0.33
(+) Significantly Greater Than Denver's Proportion, at $p < 0.05$ (-) Significantly Less Than Denver's Proportion, at $p < 0.05$			

### Preliminary Analysis of All Denver TOD Sites

As mentioned, the rationale for focusing on only four of Denver's TOD sites is largely related to limited resources for surveying and collecting qualitative measures of walking space. Because physical space measures of walking space are easily obtainable for many station sites, I performed a preliminary analysis of physical space measures as they relate to walking behavior for all Denver TOD sites. This preliminary analysis influenced my decision to collect data on perceived space and, due to limited resources, to choose four TOD sites to focus the analysis.

In this pilot study, physical space measures, including both walksheds and 3D walk scores, were extracted from the TOD areas of all currently operated Denver light rail stations. These physical space measures were then compared amongst each other as well as with actual walking behavior to see if physical space measures are related and to see if space played a role in pedestrian mobility. Walking behavior data were taken from the Denver Metropolitan Planning agency, Denver Regional Council of Governments' (DRCOG) 2009 "Who is TOD?" study, and included average number of cases walked per week. Due to the nature of the 3D score data, a non-parametric analog to Pearson's correlation was used—namely, Spearman's Rank Correlation—to see if there is any statistical evidence to suggest that there is a relationship between (1) the two physical space measures and walking behavior, and (2) the two metrics of physical space; see Figure 8 and Figure 9 below.

Figure 8: Preliminary Analysis—Relationship between Physical Space and Behavior

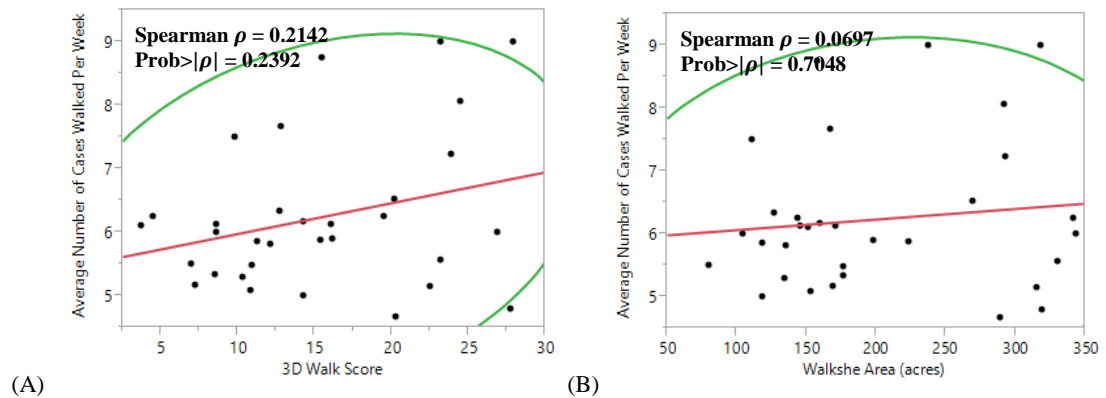
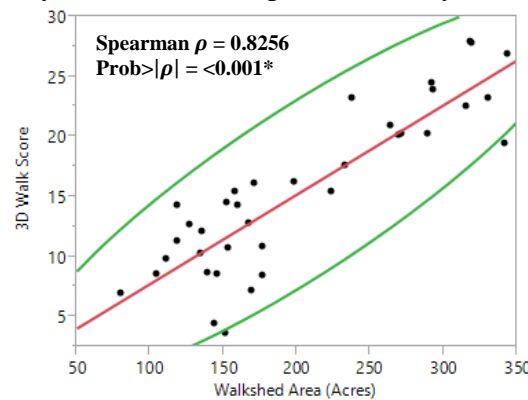


Figure 9: Preliminary Analysis—Relationship between Physical Space Measures



Two main conclusions can be drawn from this pilot study. First, there is statistically significant evidence to suggest that walkshed size and 3D walk scores are related, whereby higher walksheds are associated with better walk scores. Therefore, these two measures of physical space are related. Second, based on the results from the Spearman's Rank correlation testing for the relationship between physical space measures and walking behavior, there is no statistically significant evidence to suggest that there is a relationship between physical space and walking behavior. This is a noteworthy conclusion because it suggests that, though a TOD space might be walkable according to physical metrics of walkability, this walkable space does not influence walking behavior. Clearly, as the results and graphs in Figure 6 suggest, there is something else going on that influences people's walking behavior. For these reasons, this research takes a more substantial approach to collecting and analyzing perceptions of space relationships with both walking behavior and physical space. Furthermore, these findings underscore the need for this research to focus on qualitative analysis, particularly sketch mapping, as a means to collect individual information about perceptions of space.

## **Chapter Four: Methods**

In order to answer my four research questions pertaining to pedestrian mobility in Denver, this research utilizes mixed methods, including both traditional and qualitative GIS. In sum, there are three GIS methods used—(1) the 3D walk index, (2) walkshed analysis, and (3) survey questionnaires and sketch mapping. Though the method is inherently mixed, the 3D walk index and the catchment area analysis make up the traditional, more quantitative GIS approach while the survey and sketch mapping are more qualitative GIS in nature. Each of these methods is used in combination to some degree to answer my four research questions. Explained in this section are the methods utilized in more detail. Given the results of these methods, this chapter is followed by an analysis chapter where the specific statistical analysis methods used to answer each research question are discussed more specifically.

### **3D Walk Index**

In order to calculate general walkability scores for each of the TOD sites, I deployed the walkability index developed by Frank et al. (2005) for each TOD site. This index uses a formula that takes the sum of the z-scores of population density, intersection density, and land use mix (see Equation 1). The result of the index is a range of values from low to high walkability that varies depending on the relative variability of the input datasets.

$$\begin{aligned}
\text{Walk Index} = & (6 * \text{Z-score of Land Use Mix}) \\
& + (\text{Z-score of Population Density}) \\
& + (\text{Z-score of Intersection Density})
\end{aligned}$$

Equation 1: 3D Walk Index (Frank et al. 2005)

However, before this index in Equation 1 can be computed, a series of preliminary GIS methods were performed. Reviewed below is an overview of some of the main GIS processes that were completed to get the 3D data ready for index computation.

#### *Population Density*

Population density was collected using 2010 US Census data at the smallest possible spatial unit (the block level) and aggregated it to each TOD half-mile buffer. Then, using all intersecting blocks of each TOD, population density was calculated as the sum number of people per sum block area.

#### *Intersection Density*

Intersection density was self-created by collecting intersection data at every street intersection, and because every TOD site has the same area, based on the half-mile buffer radius, we did not have to equalize the number of intersections by the area of the TOD, and therefore, compared each TOD site strictly by the number of intersections.

#### *Land Use Mix*

Land use mix is the most complicated calculation of the 3D index. In order to quantify the mixture of land uses in a given area of land, the best equation to use is an entropy equation. Entropy equations for land use mix essentially generate measures

reflecting the evenness of distribution for different land use types, or the heterogeneity of land uses. The formula for the equation is computed as follows:

$$H = -1 \frac{\sum_{i=1}^n p_i * \ln(p_i)}{\ln(n)}$$

Equation 2: Land Use Mix Entropy Equation (adopted from Christian et al. 2011)

Where H is the land use mix entropy value,  $p_i$  is the proportion of the area covered by land use  $i$  against the summed area for land use classes of interest (including  $i$ ), and  $n$  is the number of land use classes of interest, except for those zoned “mixed use” (Christian et al. 2011). This entropy equation results in scores ranging from 0 to 1, from the most homogeneous to the most heterogeneous. For those land parcels zoned as “mixed use,” the entropy value was given a score of 1 (total heterogeneity). The final entropy score for each TOD is the sum of the proportion of the mixed-use land area entropy score (1) and the proportion of the entropy values calculated using the above equation for all other land uses of interest (Equation 2).

### **Catchment Area Analysis**

My second method used to collect information on the distance-oriented measures of walkability is a catchment area analysis. A catchment area analysis is a GIS method that identifies the catchment area (also known as walkshed) of a given location (i.e transit stop) based on time and travel demand (Anderson and Landex 2009). In order to calculate the walksheds of the TOD sites, I used the GIS Network Analysis tool in ArcMap to create catchments, or ‘service’ areas, for each transit station and adjusted the results based on the presence of barriers or facilitators. Instead of a straight-line buffer of half-

mile, the catchment area analysis method allows me to identify the actual pedestrian walkability area based on the layout of the street network (Anderson and Landex 2009; Bejleri et al. 2010). Furthermore, with this technique, I was able to adjust the catchment area based on potential barriers (i.e. interstates, fences, etc.) or facilitators (i.e. parks, pedestrian bridges, etc.) in order to represent the true pedestrian walkshed of each TOD site. After calculating the walksheds in a GIS, I use the catchment area of each TOD as an indicator for how walkable the TOD is.

### **Surveys and Sketch Mapping**

To address the aspects of individual walking behavior and perceptions of space, I took a more qualitative route. More specifically, I created an open and closed question survey to collect information about individuals travel behaviors and perceptions of space, see Appendix B. The inspiration for this survey comes from a report from Agrawal, Schlossberg, and Irvin (2009), which had a great deal of success and high response rate. The survey used in this research models much of their same structure, including the integration of sketch mapping elements to capture individual's walking geographies.

The survey was handed out to participants at each of the four TOD sites' train stations during the first two weeks of December and the first week of January, and on weekday morning and evening peak travel times. In order to control for weather influences on the number of walkers across each station site, each station was surveyed on warm and non-inclement weather days, where the daily high temperatures were at least 50-degrees Fahrenheit (10-degrees Celsius). Frequency of train arrivals were also taken into consideration when designing the surveying approach, and instead of requiring

onsite completion, participants were given a survey packet with a pre-addressed and stamped envelopes to mail back their completed surveys at their convenience. A total of 100 surveys were handed out at each station, with the exception of 27<sup>th</sup> and Welton. Due to a low pedestrian flow, I was only able to hand out 76 surveys at the 27<sup>th</sup> and Welton site, despite many more hours devoted to handing out surveys at this station than any of the other stations.

The participant samples I pulled from were light rail riders as they are waiting for the train. These individuals included both walkers and non-walkers with personal knowledge or experience of the area. Including non-walkers in the survey creates a more robust survey capable of not only capturing the perspectives of walkers, but also the perspectives of the non-walkers, thus, shedding light on the barriers to their pedestrian mobility. Survey questions covered aspects related to basic demographics, actual walking behavior (e.g. frequency, origins, and routes), and those relating to perceptions of walking in the surrounding TOD area.

Compared to a traditional survey, this survey incorporated a couple of sketch mapping components in addition to the traditional question types. Sketch maps are cartographic representations of individuals or groups' spatial experiences overlaid on a geographically referenced basemap (Boschmann and Cubbon, 2014). The survey questionnaire included four spatially referenced basemaps of each TOD surrounding area. On each basemap, survey participants were asked to draw different aspects of their individual walking cartographies, including those pertaining to both their perceptions of space and individual walking behavior. Table 3 below highlights the sketch elements that



were included in the survey, indicated by map number, the drawing type (i.e. point, line, or polygon) and the desired measure of pedestrian mobility (i.e. behavioral or perceptions of space). It is important to note that the sketch elements included in the survey were inspired by Lynch’s five elements of mental maps (i.e. paths, nodes, districts, landmarks, and edges), as explored in Chapter Two, and tailored to fit the context of sketch mapping pedestrian mobility.

Table 3: Sketch Elements Used in Survey Questionnaire

Map No.	Sketch Type	Marking	Mobility Measure
1	Origin	Point	Behavior
1	Route(s) Walked to Station	Line	Behavior
2	Routes(s) Regularly Walked	Line	Behavior
3	Safe/Good Walking Areas	Polygon	Perceptions
4	Unsafe/Bad Walking Areas	Polygon	Perceptions

A total of four sketch basemaps were integrated into the survey design. Each sketch type was given its own sketch basemap, with the exception of origin and routes walked to the station, which were combined into one sketch map asking participants to “sketch the route(s), if any, that they walk to the station, being as specific as possible about the origin.” In the order in which they appear, the four sketch maps included in the survey design are as follows: (1) Route(s) walked to the station and specific origin, (2) route(s) normally walked within a given week, (3) good or safe areas for walking, and (4) bad or unsafe areas for walking. It is important to note that results from a test survey indicated that participants commonly grouped quality and safety together when perceiving an area to be good or safe for walking. Therefore, instead of separating the

two, this survey combines quality and safety together when asking participants to sketch their perceptions of walking space.

The sketch maps were designed in combination with survey questions; therefore, the survey collected data related to behavior and perceptions of the built environment from both the survey questions and the sketch maps. For example, for information related to walking behavior, I asked survey respondents to draw the route(s) which they walked that day (if any) onto the sketch map, and coupled with this sketch, the survey also included closed-ended questions related to frequency of walking behavior. For aspects related to perceptions of space, the sketch map component asked participants to shade in areas that they feel safe or unsafe to walk, and as part of the survey questions, participants were also asked a couple of open-ended questions that gauges why they perceive these areas as safe or unsafe as well as closed-ended rating questions relating to their attitudes and perceptions of walking in the area. Integrating the survey questions with sketch mapping allows me to get a better sense of pedestrians' perceptions and experiences of walking space as well as their actual walking behavior. To get an idea of the perceived and behavioral questions addressed in the survey, please see Table 4 and Table 5, respectively.

Table 4: Survey Questions Addressing Perceived Space

Perception Questions	Question Type	Choices
Overall perceptions and/or experiences walking in the area	Open	--
Feeling capable of walking in the area	Closed	Agreement Scale*
Feelings of safety from traffic when walking in the area	Closed	Agreement Scale*
Feelings of safety from crime when walking in the area	Closed	Agreement Scale*
Thoughts of the neighborhood being ideal for walking	Closed	Agreement Scale*
Feelings that walking is the fastest way to get around in this area	Closed	Agreement Scale*
Reasons for thinking the sketched areas are good/safe for walking (if sketched)	Open	--
Reasons for thinking the sketched areas are bad/unsafe for walking (if sketched)	Open	--
*Agreement Scale is based on the following gradient: Strongly Agree, Somewhat Agree, Somewhat Disagree, and Strongly Disagree		

Table 5: Survey Questions Addressing the Behavioral Dimension

Behavior Questions	Question Type	Choices
Normally walk to the station	Closed	Yes/No/Sometimes
Normally walk to get around the area	Closed	Yes/No/Sometimes
Frequency of walking in the area	Closed	Freq. Categories*
Reasons for not walking in the area	Open	--
*Freq. Categories are based on the following gradient: 5-7 Times a Week, 3-4 Times a Week, 1-2 Times a Week, A Few Times a Month, Once a Month, Rarely Ever.		

### Sketch Quality Control

The survey was designed in such a way that allows individuals to draw the sketch maps themselves, without my assistance. Without a moderator to control the sketch mapping process upon the creation of the sketch maps, I had to control the sketch maps to order to ensure data quality during the data processing phase. To do this, I controlled for what Kevin Lynch terms as “imageability.” According to Lynch, imageability is essentially a term representing three components of a mental map image: identity, structure, and meaning (Lynch 1960). In terms of my sketch map quality control, for a sketch to be used in this research, it must have a clear sense of imageability. Thus, each

map was individually assessed to determine its rate of imageability. The imageability assessment is based on a schema that follows the three components of Lynch's definition for imageability. First, the image must be identifiable and distinct from other things (a separable entity). Second, the image must have some sort of structural spatial pattern that relates the object(s). Finally, the image must have some sort of meaning, whether practical or emotional, to the observer (Lynch 1960). Lynch used these three components—identity, structure, and meaning—as a way to analyze and control the quality of his mental maps, however, these components are not reserved solely for mental map analysis. In fact, using Lynch's methodology, I translated his use of identity, structure, and meaning into my sketch map analysis and used it for sketch map quality control. Discussed below is the sketch map quality control schema created for sketch map processing in order to identify usable sketches for the composite analysis, further detailed in the following chapter.

To control for identity, I asked participants to sketch different things on separate basemaps. A total of four basemaps were included in the survey for sketching four different aspects of people's walking cartographies (routes walked to the station, routes walked within a given week, areas perceived to be good or safe for walking, and areas perceived to be bad or unsafe for walking). Any received surveys that had the exact same thing for all four maps were excluded from the composite analysis. To control for structure, the sketch must have made some sort of spatial sense with the basemap. For instance, if someone indicates their perceptions of safe areas by drawing a large box around the entire map, this sketch passed the structure quality assessment, as it is

apparent that the participant sees the entire basemap area as being safe. However, if a participant sketched something nonsensical, such as an elephant on the basemap, these sketches clearly do not have a spatial pattern consistent with the mappable area, and therefore, these kind of sketches were not included in the analysis. In addition to excluding those nonsensical images without a geography, I also controlled for structure by eliminating writing on the sketch map. The elimination of writing was done in a few different ways. First, if participants labeled their sketch, the non-geographically bound label or writing was removed from the composite analysis, leaving only their remaining sketch. Second, if participants wrote their perceptions on the basemaps, instead of sketching them, then the writing was converted into geographic space. For instance, one of the most common cases of participants writing their perceptions on the basemap, versus drawing them, was for the perceptions of space sketch maps. For instance, a common case was when people would write that the entire area is safe on the basemap. In this instance, a polygon filling the entire basemap was created to stand in as their sketch and represent their perception of space. Essentially, if this writing was referring to space, then it was converted into spatial extents and used in the analysis. Third, if a person wrote something that does not refer to their specific perceptions of the area on the map, then this writing was completely excluded from the analysis. Finally, to control for meaning, related survey questions must have been answered, in addition to the sketch drawn, because the survey responses are what will give the sketch meaning. Therefore, if the matching survey questions are not answered, but the sketches are drawn, then the sketches were not included in the composite analysis.

In addition to controlling for sketch map imageability, another way that I assessed for quality control was to determine participants' knowledge of the area's walkability. Before giving the participants the survey, I first asked them if they walked to the station (from any given origin place), and if yes, I assumed they have at least some knowledge of the TOD area, even if it is only the area that they walked through, and thus, asked if they would participate in the survey. If the participants did not walk from an origin place, I explicitly asked them if they have knowledge of the area before they are given the survey in order to gauge whether I should ask them to participate in the survey. If they answered "yes", or even "somewhat," then I gave them the survey to see if I could assess their perceptions of the area and understand why they did not walk. For the sketch images, these non-walker individuals are equally as valuable as the walkers because they provide the alternative perspectives and sketch images that may reveal important aspects of the built environment in terms of perceived walkability that might be impeding pedestrian activity in the area. Finally, as a means of sketch map quality control, individuals that answer "no" to both not walking and to not knowing the area were not surveyed, as they are seen to lack enough information related to the walkability of the area to provide meaningful sketches.

## **Chapter Five: Analysis**

Results generated from the three GIS methods—3D walk index, walksheds, and survey and sketch mapping—are analyzed in a number of different ways. Sketch maps are analyzed by creating composite maps while survey answers were transcribed and then qualitatively coded for common responses or themes. Demographic aspects of survey participants were analyzed in a variety of ways, including an examination of differences among stations and station neighborhood demographics, among perception and behavior survey responses, and among differences in sketch composite maps. Behavior and perception survey responses were tested for statistically significant relationships as well as for differences among station responses. Finally, each measure of walkability was evaluated using comparative analysis techniques allowing me to understand the relationships between different measures of walking for each station. This section details the specific analytics taken with this research.

### **Sketch Composite Mapping**

Instead of looking at individual sketches separately, I integrated the sketch maps collected from the survey into a GIS in order to create composite sketch maps, showing commonly walked or perceived areas. Creating composite maps help to identify discernable features and trends common, such as areas more commonly sketched as being safe (or unsafe) areas for walking, or density maps showing paths most commonly

traversed by participants. In order to create the composite maps, I first had to perform a number of GIS processes and tools. Majority of this individual sketch to composite mapping processes were performed using ArcGIS and were automated using python scripts in order to save time and eliminate possible human-end error. Using my analysis as a skeleton, I was able to create qualitative GIS tools for future sketch mapping analysis. Detailed in this sketching is the step-by-step GIS processes performed in order to translate individual sketch maps into composite maps or public images of pedestrian mobility.

The initial phase toward creating composite maps was to prepare the paper sketches collected for spatial analysis. First, I had to georeference the scanned paper based sketch maps. Automating georeferencing was particularly straight-forward here. Essentially, by ensuring that each station basemap had the exact same scale and placement on the survey page, I was able to determine the locations of the top and bottom corners of the 8 ½ by 11 page, and use these corner locations as control points in the automated georeferencing processes. Next, the georeferenced survey page was clipped by the map's data frame extent in order to remove the extraneous page margins and survey questions. Once the image had been clipped, I then needed to separate the sketched image from the underlying basemap. Instead of digitizing the sketches, which would have been extremely time consuming, I had each participant draw their sketches in a pink marker (which was included in the survey packet) and then I wrote a python script to have the computer recognize the pink pixels of the sketched image from the grey-scale basemap. This was performed through a simple Maximum Likelihood Classification (an ArcGIS



Spatial Analyst tool), creating an output Boolean raster, where sketched areas received a value of 1 and non-sketched areas received a value of 0.

Once the individual sketches had been classified, I still had to make a few adjustments before composite creation. Namely, I (1) had to adjust or eliminate sketches based on the outcome of the sketch map quality control assessment, and (2) control for inconsistencies in the variations of individuals' sketching. First, I needed to apply the needed changes to individual sketches, either adjustments or exclusions, based on the sketch map quality control assessment (as detailed in Chapter Four). To do so, I first converted the individual raster files into individual polygons, using the Raster to Polygon tool (from the Data Management toolset). Then, for those sketches that needed adjustments, I manually changed the vector file in an editing session, deleting words or labels, or creating all new polygons based on the individual's response. As for those sketches that needed to be excluded all together, I simply deleted the vector file. This process allowed me to exclude certain unqualified sketches from composite analysis without actually altering the original sketch image stored in the geodatabase.

Second, in addition, to controlling for imageability, I also had to control for variations in drawing styles across individuals (e.g. completely filled in, outlined only/no fill, or partial zigzag fill styles). It is important to note that utter control of variations in drawing styles on paper maps is ultimately impossible without either having a moderator present during the drawing process or without using a digital means to collect sketches. With that said, however, I was able to significantly adjust for variations in drawing styles by using the Aggregate Polygons tool (from the Cartography toolbox). This tool

essentially combines polygons within a specified distance of each other into a new aggregated polygon. This technique was particularly useful for those partially-filled in drawing styles and helped to fill in the gaps of areas that people's sketches intended or alluded to.

Next, the vectors were reconverted back into individual raster files (using the Vector to Raster tool in the Data Management toolbox) and the composite map was created based on the sum overlap for each station and each sketch map number. A self-created tool in ArcToolbox was produced in order to allow for different composite maps to be created based on any specified demographics or survey responses. Essentially this tool allows users to specify an SQL query statement from the survey results table which creates a composite image for each station and map type for only the sketches from individual's meeting the query requirements. Creating such a tool allowed me to create not only a composite map for all individuals, but also a composite for any given survey response or demographic group, such as women or those that indicated that they frequently walk 5-7 times a week.

### **Qualitative Coding of Survey Responses**

To analyze the qualitative open ended survey responses, I utilized qualitative coding techniques to identify discernable patterns in survey responses. Coding of survey responses is a common qualitative method whereby particular themes and trends from survey responses are identified and counted in order to find a preponderance of evidence that might suggest a significant behavioral or perceptual trend. Because I only had a few open ended questions, I chose to code the survey responses by hand, with a successive

checklist style procedure. As the objective researcher, I looked for evidence to suggest that a participant's answers conform to a set of core themes, both pre-determined themes as well as unbounded themes for serendipitous responses. These included a set of core responses common to all stations as well as more unique station-specific responses. Different coding schema were generated for each open-ended survey question, including reasons for not walking, why sketch areas are good/safe, why sketched areas are bad/unsafe, overall perceptions of walking in the area, and recommendations to improve pedestrian mobility in the area. After coding, I summed the total count for each theme and compared within and across each station, identifying common threads amongst stations as well as a significance for a particular response. The statistical tests used to compare within and across stations is discussed in detail at the end of this chapter.

### **Comparative Analysis of Walking Space**

Because survey and sketch map data on perceptions of space were only collected for four stations, the sample size is too low to do any statistical testing to compare the relationships between different spatial measures of walking. Instead, this research utilizes comparative and descriptive analytical approaches to capture some of the spatial relationships of pedestrian mobility across all four station study sites.

#### *Heat Map Score Chart*

Coupled with mapping each spatial measure for each TOD, I created a heat map, or score chart, for each spatial measure of walkability (general, distance-oriented, or perceived). The inspiration for this analytical technique comes from the Denver 2014 TOD Strategic Plan (Denver 2014), whereby Denver planners used a similar heat map

scoring system to determine TOD market readiness. Using this technique allows me to visualize and compare the different walkability measures across all TOD sites. Essentially, each quantitative measure of walkability is represented by a color gradient of low-to-high walkability for visual comparison. The values for the 3D scores were transferred directly into the score chart for general walkability and the percent walkshed area was used for distance oriented walkability. For both, the higher the measure, the better the walkability. As for the sketches, I computed the total area of good/safe sketches subtracted by the total area of bad/unsafe areas. Instead of using all sketches, however, I used the “most sketched” in the calculation. Due to the nature of hand drawn sketches that introduce inconsistencies in drawing style, “most sketched” areas were defined by a 20% or more overlap in individual sketches. Subtracting the good/safe areas from the bad/unsafe areas creates numbers which reflect how much of the TOD area that people commonly agree to be good/safe compared to the areas identified as bad/unsafe. The idea here is that the larger the number the more TOD area is good/safe for walking, whereas a low negative number signifies that more of the TOD is commonly seen as bad for walking. This good versus bad computation was performed in ArcGIS, by first selecting all of the composite rasters’ cells that make up 20% agreement, where the percentage is based on the composite sample size (the number of maps used to make the composite density raster for each station and map type). Then, for only the area of 20% agreement, I calculated the percent TOD area and subtracted the bad/unsafe composite for a particular station from the corresponding good/safe composite. In addition to most sketch areas, I also created another heat map chart of the survey answers that relate to perceived space.

In total, perceived space measures include the good versus bad calculation, closed-question survey answers, and an open-ended answer of overall perception of the TOD. Creating these heat charts allows for a better comparison of walking spaces across all TODs and enables me to make some basic descriptive analysis between the different typologies.

#### *Comparative Distribution Charts*

In addition to the heat map score cards, I also created an overlay plot and bubble chart to compared spatial measures of walking among each station. The overlay chart uses multiple axis for different ranges and overlays different variables into the same chart in order to compare the score across each station category. The bubble chart allows me to visualize different scores together using a size bubble to represent a different variable than the y axis.

#### **Demographic Analysis**

##### **Z-Test for Difference in Population Proportions for Neighborhood and Sample Population Proportions of Demographic Variables**

Z-tests for differences in population proportions were computed in order to determine if there is a statistically significant difference in the proportions of demographic variables between the surrounding station neighborhoods and the sample of individuals collected in the survey. This test is appropriate because it is used to test the difference between two populations based on some single categorical characteristic, such as a demographic characteristic. The sampling distribution of the proportions is approximately normal with a mean of  $\mu_{\hat{p}_1 - \hat{p}_2} = \pi_1 - \pi_2$  and a standard error of

$SE_{\hat{p}_1 - \hat{p}_2} = \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}$ , whereby  $\mu_{\hat{p}_1 - \hat{p}_2}$  is the difference between the two population means,  $\pi$  is the hypothetical proportion of the population,  $\hat{p}$  is the sample proportion and corresponds to the sample's population proportion ( $\pi$ ), and  $n$  is the sample size. The null hypothesis is that there is no difference among the demographic variables between the TOD neighborhood and the survey sample ( $H_0: \pi_1 = \pi_2$ ), while the alternative hypothesis is that there is a difference ( $H_0: \pi_1 \neq \pi_2$ ). The test statistic used to test the null hypothesis is  $Z_{test} = \frac{(\hat{p}_1 - \hat{p}_2) - 0}{SE_{\hat{p}_1 - \hat{p}_2}}$ . For each test, if the  $Z_{test}$  is greater than or less than the bounds of  $Z_{\alpha=0.05, df}$ , then I can reject the null hypothesis in favor of the alternative. Otherwise, I will fail to reject the null hypothesis with no statistically significant evidence to suggest that there is a difference between the survey sample demographics and the overall TOD area.

The demographic group variables used in these test were gender, age group, race, and income. The gender variables used were female and male. Age group was divided into three age range groups—18 to 35 year olds, 36 to 50 year olds, and those 51 or older. Due to limited variability in responses, race was broken up into only three main categories—Caucasian, Hispanic, and African American. Finally, income was further grouped based on low, moderate, and high income ranges, whereby low includes 10-30k and 30-50k, moderate income include 50-70k and 70-90k, and high includes 90-110k and 110k+. In total, eleven z-tests for differences in population proportions were run for each demographic and each station, totaling forty-four tests for all stations.

The neighborhood selection was performed in ArcGIS, whereby all block groups intersecting the TOD buffer were selected and aggregated by station. The demographic data for the larger TOD neighborhood area comes from the 2010 U.S. Census and the 2012 American Community Survey (ACS) for income data. Due to lack of data available on the proportions of personal relations with the TOD (e.g. live only or work only), I could not use this demographic variable in the demographic analysis.

### **Pearson's Chi-Squared Test for Demographic Relationships among Stations**

The Pearson's Chi-Squared test tests whether or not there is a relationship between two variables based on the creation of a contingency table and the computation of the probability of an expected result compared with the observed results. Pearson's Chi-Squared tests were performed on demographic variables in this research to see (1) if there is a statistically significant difference in various demographic groups and the station sites, (2) if there is a difference in demographic groups and walking behavior, and (3) if there is a difference in demographic groups and perceptions of space. For each demographic group, the null hypothesis is that the probability of each demographic group outcome is the same for each station/behavior/perception category ( $H_0: \pi_{ij} = \pi_i^r \pi_j^c$ ), while the alternative is that the probability of at least one demographic group outcome is different between the station/behavior/perception categories ( $H_a: \pi_{ij} \neq \pi_i^r \pi_j^c$ ).

When the null hypothesis is true, the sampling distribution is a Chi Square distribution with degrees of freedom equal to  $(r-1)(c-1)$ , where  $r$  is the number of rows and  $c$  is number of columns in the contingency table. The test statistics is  $\chi^2 = \sum \frac{(E-O)^2}{E}$ , where  $E$  is the expected frequency and  $O$  is the observed frequency. Expected frequencies

are computed for each cell based on the assumption that there is no relationship. Using this contingency table, the expected frequency for a cell is equal to the product of its row's total and its column total, divided by the total number of observations.

Assumptions of the chi-squared test is that it follows the approximate chi-squared distribution and that in order for the statistic to hold, the total number of subjects should be at least 20 and the total number of subjects in each cell should be at least 5. Because of this limitation, demographics were grouped together into demographic groups.

Demographics were grouped into the following groups: gender (male or female), age group (18-35, 36-50, and >50), income (low, moderate, and high), and personal relation to station (live, work, both, and neither).

#### *Test for Differences in Station Demographics*

First, Chi-squared tests were run in order to see if there are any differences in the demographic makeup of survey participants across each station. For each demographic group, the null is that there is no significant relationship between demographic groups and station type while the alternative is that there is a significant difference among the demographic groups across all stations.

#### *Test for Differences in Demographics and Walking Behavior*

Second, Chi-square test were run in order to determine if there is a difference in walking behavior and demographic group. For each demographic group, the null hypothesis is that there is no significant difference between demographics and walking behavior, while the alternative is that there is a significant difference. The walking behavior categories used here were derived from the answers from the closed-question



survey answer. Walking behavior answers were grouped into the following groups: yes or no/sometimes (for the questions asking whether or not individuals walk to the station or walk within the TOD area), and frequent and infrequent, whereby frequent walkers are those that indicated that they walked 3-7 times a week, and infrequent walkers walk 2 or fewer times a week.

#### *Test for Differences in Demographics and Perceptions of Space*

Finally, Chi-square tests were run in order to determine if there is a difference in perception of space and demographic group. For each demographic group, the null hypothesis is that there is no significant difference between demographics and perception of space, while the alternative is that there is a significant difference. The perception of space categories used here were derived from the closed-question survey answers.

Perception of space answers were grouped into the following groups: agree and disagree (compared to the gradation of strongly agree, somewhat agree, somewhat disagree, and strongly disagree).

#### **Sign Test for Demographic Differences in Composite Sketch Maps**

Another way that I tested for demographics was through differences in the composite sketch maps. Testing for differences in composite sketch maps allowed me to see if there were any similar patterns of behavior or perceptions of space among a particular demographic group that is spatially different from other demographic groups. Using self-created tools, composite maps were generated for each demographic group, however, only the ones that appeared to be visually different were tested. To test the demographic variables that looked different among the composite sketches, I first

aggregated each of the demographic composites into a fishnet polygon, extracting values of the cell count to each polygon cell, based on the majority value. I did this using a 500 by 500 foot fishnet and using the ArcGIS Zonal Statistics tool from the Spatial Analyst toolbox to calculate the median and majority cell values that fall within each 500by500 fishnet. The output of the tool created a table where I then was able to calculate the total proportion of overlap based on the number of individual sketches used to create the specific demographic composite. Because different percentages of demographics occur across each station as well as different numbers of a particular demographic variable for each sketch composite map, the value proportions were calculated on a case by case basis for each unique demographic variable and sketch map combination. Once proportions were calculated, these proportion values of demographic variables were statistically tested in JMP to see if there is a difference among the distribution of perceived space sketches across demographic groups. The non-parametric sign test was used as the matched pair's analysis to see if there is a statistically significant difference in perception of space across different demographic groups. For each demographic group and map type tested, the null hypothesis is that there is no difference across the groups and the alternative is that there is a difference between the two groups. The pairing was done spatially, based on the fishnet unique id number. The test statistic for the sign test is  $b$  which is the number of samples with a negative sign. If the null is true, the test statistic is distributed with a binomial distribution. The reason this test was used is because it makes very little assumptions about the nature of the distribution of the data being tested, and therefore, is very applicable for a demographic comparison of perceived space.

Moreover, the sign test is much less likely to reject the null hypothesis than any other test; therefore, if it concludes that there is a statistic difference, then there likely really is a difference.

## **Statistical Analysis of Perception and Behavior**

### **Pearson's Chi-Squared Test for Behavioral and Perception Relationships across Stations**

In addition to testing demographic variables, Pearson's Chi-Squared tests were also performed on behavioral and perception survey responses across the four stations in order to see if there are statistically significant relationships between (1) the station and walking behavior, (2) the station and perception of space, and (3) between behavior and perception. For each, the null hypothesis is that the probability of each group outcome is the same for each category ( $H_0: \pi_{ij} = \pi_i^r \pi_j^c$ ) while the alternative is that the probability of at least one group outcome is different between the categories ( $H_a: \pi_{ij} \neq \pi_i^r \pi_j^c$ ).

#### *Differences in Walking Behavior across Stations*

First, Chi-square tests were run in order to determine if there is a difference in walking behavior across each station. For each station, the null hypothesis is that there is no significant difference between station and walking behavior, while the alternative is that there is a significant difference. The walking behavior categories used were derived from the closed-question survey responses, including actual frequency of walking, and whether or not someone walks to the station and within the area. Walking behavior answers were grouped into the following groups: yes or no/sometimes (for the questions

asking whether or not individuals walk to the station or walk within the TOD area), and frequent and infrequent, whereby frequent walkers are those that indicated that they walked 3-7 times a week, and infrequent walkers walk 2 or fewer times a week.

#### *Differences in Perception of Space across Stations*

Second, Chi-square tests were run in order to determine if there is a difference in perception of space across the four station study sights. For each station, the null hypothesis is that there is no significant difference between station and perception of space, while the alternative is that there is a significant difference. The perception of space categories used here were derived from the closed-question survey answers. In order to make their group numbers large enough to run the test, perception of space answers were grouped into the following groups: agree and disagree (compared to the gradation of strongly agree, somewhat agree, somewhat disagree, and strongly disagree).

#### *Relationship between Behavior and Perception across Stations*

Third, Chi-square tests were run in order to determine if there is a significant difference in walking behavior and perception of space across the four stations. For each walking behavior group, the null hypothesis is that there is no significant difference between behavior and perception, while the alternative is that there is a significant difference. Both the walking behavior and the perception of space categories used here were derived from the closed-question survey answers. The grouping of behavior and perception categories is discussed in detail in the two subsections above.

## **Chapter Six: Results**

This section presents the results of my mixed methods analysis. In the first section, basic survey responses and statistics are explored, presenting general trends and differences in survey demographics, perception, and behavioral responses across and within the four station sites. In the following section, the composite sketch maps are presented. In the third section, the spatial measures of walking (general, distance-oriented, and perceived) are compared and analyzed for spatial trends and relationships. Next, relationships between perceived space and behavior are explored in the fourth section. And finally, the results chapter concludes with demographic trends in behavior and perception, both based on survey questions and demographic sketch map composites.

### **Station Survey Results**

The number and response rate of surveys across each station vary, but in general, Louisiana Pearl and Union Station both had similarly high numbers and response rates of over 50%. Comparatively, Alameda and 27<sup>th</sup> and Welton had similarly low response rates and fewer surveys mailed back. However, when compared to Alameda, 27<sup>th</sup> and Welton exhibits a higher response rate. This is because fewer surveys were given out at the 27<sup>th</sup> and Welton station due to a significantly lower pedestrian traffic volume at this station than any other. The sample of surveys mailed back and response rates for each station can

be seen in Table 6. In total 372 surveys were distributed across all four stations and 179 surveys were received, totaling a 48% response rate overall.

Table 6: Survey Response Samples

Station	Sample ( <i>n</i> )	Response Rate
Alameda	36	36%
Louisiana Pearl	57	57%
Union Station	56	56%
27th and Welton	30	40%

### Station-Demographic Results

Of the 179 surveys received, the demographic makeup is largely homogeneous. Table 7 below details the numbers and percentages of the different demographic groups for each station. Demographic homogeneity could be attributed to a number of forces, including rising market values of homes in TOD areas, the costs of using light rail as a mode of transport, the geographic locations of each TOD area within the urban fabric, or the demographics of walkers or of those who participate in a survey about walking.

Results suggest that similarities among station demographics include gender, race, income, and age, while differences reside mostly within the ratios of individuals that live or work within the TOD areas. First, the percentages of male and females are about even, although 27<sup>th</sup> and Welton has around a 60:40 makeup of women, while the trends for Alameda are reversed with more men. Most stations seem to have a similarly even split among all income groups, however, Louisiana and Union Station have a slightly larger proportion of high income (90 plus thousand a year) individuals than other stations. For ages, all stations have larger proportions of individuals under the age of 34, and all, except Union Station, have their smallest proportion of individuals being over the age of 50. Similarly, all stations have the largest proportion of Caucasians than any other group,

though 27<sup>th</sup> and Welton does have larger proportions for other races than any other station. Finally, the demographic percentages seem to show that most differences across stations are in terms of one's geographic relation to the station. Both Alameda and Louisiana Pearl have their highest percentages of individuals that live only within the TOD. Union Station has the largest number of individuals that indicated that they neither live nor work within the TOD, and 27<sup>th</sup> and Welton has an evenly mixed group of people that live only, work only, both live and work, and neither live nor work. The statistical results from the Pearson's chi-squared tests for (1) the difference in survey sample demographics across stations, and (2) the difference in survey sample demographics and surrounding neighborhood demographics are discussed below.

Table 7: Station Survey Demographics, Summary Statistics

		<b>Alameda</b>		<b>Louisiana Pearl</b>		<b>Union Station</b>		<b>27th &amp; Welton</b>	
		<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>
<b>Gender</b>	<b>Female</b>	13	36.1	25	43.9	27	48.2	19	63.3
	<b>Male</b>	23	63.9	32	56.1	29	51.8	11	36.7
<b>Income</b>	<b>Low</b>	11	30.6	17	29.8	19	33.9	7	23.3
	<b>Moderate</b>	10	27.8	15	26.3	13	23.2	10	33.3
	<b>High</b>	11	30.6	23	40.4	21	37.5	10	33.3
<b>Age Group</b>	<b>18 to 34</b>	17	47.2	31	54.4	22	39.3	12	40
	<b>35 to 50</b>	11	30.6	12	21.1	9	16.1	9	30
	<b>51+</b>	6	16.7	11	19.3	17	30.4	3	10
<b>Live or Work</b>	<b>Both</b>	1	2.8	0	0.	2	3.6	7	23.3
	<b>Live Only</b>	27	75	44	77.2	10	17.9	11	36.7
	<b>Work Only</b>	3	8.3	12	21.1	10	17.9	7	23.3
	<b>Neither</b>	4	11.1	1	1.8	31	55.4	4	13.3
<b>Race</b>	<b>Caucasian</b>	30	83.3	45	78.9	42	75	18	60
	<b>Hispanic</b>	2	5.6	4	7.0	5	8.9	3	10
	<b>African American</b>	2	5.6	1	1.8	3	5.4	3	10
	<b>Other</b>	2	5.6	3	5.3	4	7.1	3	10

### *Demographic Differences in Survey Participants among Stations*

The results from the contingency table and computation of the Pearson's chi-squared test show, for example, that there is no statistically significant distinction between age, income, gender, and ethnic/racial groups across all four stations. There is, however, evidence to suggest that the stations vary among individual's geographic relation to the station. Given the Chi-squared test results, I rejected the null hypothesis in favor of the alternative that there is a difference among stations and individual geographic relationship to the station. As supported by the contingency table, Union Station uniquely differs from all other stations because it exhibits a higher than normal number of people who indicated that they "Only Work" in the TOD area. At the same time, results suggest that 27<sup>th</sup> and Welton has a higher proportion of individuals who indicated that they both "Live and Work" in the TOD area. As for Louisiana Pearl and Alameda stations, most people surveyed indicated they only live within the TOD. For the contingency tables, chi-squared results, and p-value statistics, please see Appendix C.

### *Survey Sample and Neighborhood Demographic Differences*

Of these 44 tests run for differences population proportions between the survey sample and the surrounding neighborhood demographics, I was only able to reject the null hypothesis 7 times—2 from Alameda, 2 from Louisiana Pearl, 3 from Union Station, and 0 from 27<sup>th</sup> and Welton. Therefore, 38 of the tests, including all of 27<sup>th</sup> and Welton's demographics, indicate that given an alpha of 0.05, there is no statistically significant evidence to suggest that the demographic sample collected from the survey is from a different population than the surrounding neighborhood demographics. In other words,



for most of the demographic variables, the survey of participants accurately reflect the surrounding neighborhood's demographics. As for the 7 tests that indicate statistical significance, only 3 out of 11 demographics appeared to be significantly different from the TOD neighborhood—the demographic groups are ages 35 to 40, Caucasian, and Hispanic. The z-score and p-values for each of the 44 tests can be seen in Appendix C. The results of the z-tests show that both Louisiana Pearl and Union Station have lower numbers of individuals with ages 35-50 years old when compared to the surrounding neighborhoods' proportions. Similarly, both Alameda and Union Station survey demographics collected have lower proportions of Hispanic representation than the surrounding neighborhood's Hispanic proportions. Finally, Alameda, Louisiana Pearl, and Union Station all had significant results for the proportion of Caucasian population. From the individuals surveyed, Alameda and Union Station samples show a much greater percent of Caucasians sampled than from the proportions of Caucasians in their surrounding neighborhoods. In contrast, Louisiana Pearl's Caucasian survey proportions is actually much lower than the surrounding neighborhood's proportions, though the proportion of Caucasians sampled is still quite large (78.9%). Table 8 details the population proportion differences between the survey and the neighborhood for all statistically significant results.

Table 8: Statistically Significant Population Proportion Differences

	<b>Alameda</b>		<b>Louisiana Pearl</b>		<b>Union Station</b>	
	<i>Survey</i> (%)	<i>Neighborhood</i> (%)	<i>Survey</i> (%)	<i>Neighborhood</i> (%)	<i>Survey</i> (%)	<i>Neighborhood</i> (%)
<b>35to50</b>	-	-	21	41	16	44
<b>White</b>	83	37	79	87	75	60
<b>Hispanic</b>	6	57	-	-	9	27

## Perception Responses to Closed-Ended Questions

The numbers and percentages of those that agreed or disagreed with five perception rating questions can be seen in Table 9. It is important to note that similarities in rating responses of perception questions could be related to the survey response bias, whereby walkers are more likely than non-walkers to fill out a survey on walking. Given the potential bias and similarities between station responses, three perception differences stand out across the four stations—(1) perception of safety from crime, (2) perception of the neighborhood being great for walking, and (3) perception on walking being the fastest mode of travel. The statistical significance of these three perceptions are discussed below.

Table 9: Closed Perception Questions, Summary Statistics

		<b>Alameda</b>		<b>Louisiana Pearl</b>		<b>Union Station</b>		<b>27th and Welton</b>	
		<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>
<b>Capable of Walking in the Area with Ease</b>	Agree	28	77.8	54	94.7	52	92.9	27	90
	Disagree	7	19.4	3	5.3	4	7.1	3	10
<b>Feel Safe from Traffic</b>	Agree	24	66.7	46	80.7	48	85.7	26	86.7
	Disagree	11	30.6	11	19.3	7	12.5	4	13.3
<b>Feel Safe from Crime</b>	Agree	26	72.2	53	93	51	91.1	18	60
	Disagree	9	25	4	7	5	8.9	12	40
<b>Neighborhood is Great for Walking</b>	Agree	28	77.8	53	93	48	85.7	20	66.7
	Disagree	7	19.4	4	7.0	8	14.3	10	33.3
<b>Walking is the Fastest Mode</b>	Agree	25	69.4	35	61.4	48	85.7	20	66.7
	Disagree	10	27.8	22	38.6	7	12.5	10	33.3

### *Pearson's Chi-Squared Test Results for Station-Perception Relationships*

Results from the Pearson's Chi-squared test for relationships closed-question perception responses among the four stations provide some interesting points of discovery. In total, five tests were run for the five rating-based perception questions—(1) *I am capable of walking in the area with ease*, (2) *I feel safe from traffic*, (3) *I feel safe from crime*, (4) *I think this neighborhood is great for walking*, (5) *Walking is the fastest*

way to get around this area. Of these five tests, three proved to be statistically significant among the response categories of agree and disagree for the four station sites. See Appendix C for the results. The first two rating-questions (*I am capable of walking with ease* and *I think the area is safe from traffic*) did not conclude with any statistically significant evidence to suggest that there is a difference in agreement and disagreement of perceptions of walking space among the four stations. The last three questions, however, did conclude with statistically significant evidence to reject the null hypothesis, see Table 10. These results suggest that at least one of the stations' participant samples differs in the perceptions of the surrounding TOD site, and by examining the contingency table, we can determine which stations differ from the rest. Larger proportions of 27<sup>th</sup> and Welton and Alameda participants disagreed that the area is safe from crime, with 27<sup>th</sup> and Welton, showing the largest difference from other stations in having the most crime safety disagreement. Similarly, larger proportions of 27<sup>th</sup> and Welton disagree that the area is great for walking. Finally, perhaps not surprisingly due to its downtown setting, Union Station has significantly more proportions of individuals that agree that walking is the fastest mode of travel to get around in the area.

Table 10: Statistically Significant Results for Station-Perception

<b>Question</b>	<b>Chi-Squared Value</b>	<b>P-value</b>
<i>Feel safe from crime</i>	19.876	0.0002
<i>This area is great for walking</i>	10.501	0.0148
<i>Walking is the fastest mode in this area</i>	10.028	0.0183

## Perception Responses from Open-Ended Questions

### *Trends across All Stations*

Coupled with each sketch map, the survey asked people to provide an open-ended response as to why their sketched areas are particularly good/safe for walking, or bad/unsafe for walking. In Table 11, the top 5 trends in open responses to why people perceive areas to be good/safe and bad/unsafe are listed, ranked by reoccurrence. Based on these results, people consider good/safe walking areas to be areas with a heavy presence of other pedestrians, ample amounts of lighting, light automotive traffic, good pedestrian infrastructure, and plenty of destinations. At the same time, areas most commonly agreed to be bad/unsafe for walking are those areas with car-dominated traffic, many homeless and transient individuals, bad or no lighting, poor pedestrian infrastructure. Interestingly, the number five reason that areas were reported to be bad/unsafe for walking was that areas are particularly bad/unsafe at night, rather than in the daytime.

Table 11: Top 5 Coded Perceptual Responses across All Stations, Ranked by Proportional Weight

	Rank	Response
Good/Safe Areas	1	Other People/ High Pedestrian Traffic
	2	Good Lighting
	3	Light Automobile Traffic
	4	Good Pedestrian Infrastructure
	5	Destinations
Bad/Unsafe	1	Heavy Traffic
	2	Many Transients/Homeless
	3	Bad lighting
	4	Bad Sidewalks
	5	Night vs Day

*Trends within Individual Stations*

Table 12: Coded Responses within Stations for Safe/Good Areas, Ranked by Proportion

	Rank	Response	P
<b>Alameda</b>	1	Other People/Pedestrian Traffic	22.2%
	1	Good lighting	22.2%
	1	Destinations	22.2%
	2	Good Pedestrian Infrastructure	19.4%
	2	Residential	19.4%
	3	Light Traffic	13.9%
	4	No problems	11.1%
	4	Safe Neighborhood	11.1%
<b>Louisiana Pearl</b>	1	Light Traffic	40.4%
	2	Good Pedestrian Infrastructure	28.1%
	3	Safe Neighborhood	22.8%
	4	Good lighting	17.5%
	4	Residential	17.5%
	5	No problems	14%
	6	All Areas are Safe	12.3%
<b>Union Station</b>	1	Other People/Pedestrian Traffic	41.1%
	2	Good lighting	25%
	3	Good Pedestrian Infrastructure	17.9%
	4	Destinations	12.5%
<b>27th &amp; Welton</b>	1	Other People/Pedestrian Traffic	23.3%
	1	Good lighting	23.3%
	2	Light Traffic	20%
	3	Destinations	13.3%
	3	All Area Are Safe	13.3%
	4	Good Pedestrian Infrastructure	10%
	4	Residential	10%
	4	Families	10%

Table 13: Coded Responses within Stations for Unsafe/Bad Areas, Ranked by Proportion

	Rank	Response	P
<b>Alameda</b>	1	Bad lighting	38.9%
	2	Construction	25%
	3	Many Transients/Homeless	19.4%
	4	Bad Sidewalks	16.7%
	5	Night vs Day	11.1%
<b>Louisiana Pearl</b>	1	Heavy Traffic	56.1%
	2	Bad Sidewalks	22.8%
	3	All Areas are Safe, None are Unsafe	12.3%
	4	Broadway	10.5%
	4	Louisiana, Buchtel & Washington	10.5%
<b>Union Station</b>	1	Many Transients/Homeless	26.8%
	2	Heavy Traffic	21.4%
	3	Night vs Day	14.3%
	4	Bad lighting	10.7%
<b>27th &amp; Welton</b>	1	Many Transients/Homeless	26.7%
	2	Heavy Traffic	16.7%
	3	Bad lighting	13.3%
	3	All Safe/None	13.3%
	3	Drug Dealers	13.3%
	4	Few People	10%
	4	Crime/Violence	10%
	4	Less Wealthy	10%
	4	Unmaintained	10%

### *Alameda*

Alameda’s top four responses for good/safe areas largely follows the same trends as the top five common responses across all stations—including heavy pedestrian traffic, good lighting, lots of destinations, and good pedestrian infrastructure. In addition to these top responses, unique response given for good/safe areas is that the areas are good/safe because they are residential (19.4%) or because they are in a “safe neighborhood” (11.1%).

As for bad/unsafe areas, Alameda’s survey participants mentioned unique aspects related to the station, and therefore, did not show up on the top 5 responses for all

stations. For instance, the two highest percent response rates for good/bad areas at Alameda were bad lighting (38.9%) and construction (25%), which interestingly, construction did not make the top response list for all stations. Following this, common responses included the presence of homeless populations (19.4%) and lack of or poor quality pedestrian infrastructure (16.7%). Perhaps because of the poor lighting, construction, and homeless/transient individuals, people repeatedly reported that the areas are especially bad at night (11.1%). These responses are not particularly telling in terms of their relationship with the crime and traffic statistics presented in Chapter Three and mapped in Appendix A. Especially when compared to the hotspot maps in Appendix A, we can see that people identified the bad and unsafe areas in places where crime is non-existent, while at the same time, they identified good and safe areas to be the areas where crime and traffic accidents occur most frequently.

#### *Louisiana Pearl*

Louisiana Pearl's top responses for good/safe areas differs from the rest of the stations in many unique ways. First, the top response for good/safe areas from most people was light automobile traffic (40.4%), which could be attributed to the fact that the neighborhood is divided by the interstate highway. Second, the third most mentioned response was that the area is a "safe neighborhood," (22.8%). This station also had many responses related to the fact that the area is residential (17.5%), and that the areas are safe because people never experienced any problems in them (14%). Finally, it is also worth mentioning that 12% of individuals mentioned that the entire map area is safe. The fact that most of Louisiana Pearl's open ended responses on perception were so positive is

telling because it is suggestive of the actual crime and traffic statistics in this station (see Figure 7 in Chapter Three and Appendix A for the hotspot map), whereby, for both crime and traffic accidents, Louisiana Pearl scored significantly lower than any other station.

As for bad/unsafe areas, a high number of Louisiana Pearl's participants talked more about the traffic aspects of pedestrian safety than any other crime related aspect. This tendency to report automotive traffic for bad/unsafe areas is reflective in the TOD's geography, particularly because it is divided by the interstate and experiences a good deal of non-local traffic. Indeed, an overwhelming 56% of individuals reported that the areas indicated as bad/unsafe for walking are bad/unsafe due to heavy automotive traffic. Related to this, Louisiana Pearl is the only other station with specific geographic areas to appear toward the top of the percent response ranking. Two such areas, Broadway and the intersection of Louisiana, Buchtel, and Washington were repeatedly reported to be bad for traffic, both with 10.5% of responses. In addition to heavy traffic responses, poor pedestrian infrastructure was also another high ranking response for bad/unsafe areas (22.8%). Finally, 12.3% of respondents noted that no areas on the map are unsafe for walking; therefore, indicating that all areas are safe.

The Louisiana Pearl participants' high response rates for heavy traffic being the reason why areas are bad or unsafe is especially interesting when compared to the station's traffic accident statistics (see Figure 7 in Chapter Three for the frequency table and Appendix A for the hotspot density map). Surprisingly, even though an extremely large percent response rate suggested that heavy traffic was the main reason for areas being unsafe, Louisiana Pearl ranks the lowest of all four stations in terms of the total



number of accidents involving pedestrians or cyclists. At the same time, however, when we examine the hotspot density map of traffic accidents in the Louisiana Pearl TOD, we find that though there is a small total number of them as well as a low density, they are nonetheless clustered around the station on either side of I-25. The significance of this finding should not be undermined because it highlights key aspects of pedestrian perceptions in relation to real crime or traffic. On the one hand, we have found that participants continually rated heavy traffic as being a significant reason to why areas are unsafe, however, these findings are not exactly in line with the TOD's actual traffic statistics. Nonetheless, as the hotspot map in Appendix A highlights, it appears that within this relatively safe neighborhood with relatively few accidents involving pedestrians or cyclists, we do find the largest number of accidents within regions buffering the interstate and station, including the intersection of Louisiana, Buchtel, and Washington that was commonly identified by survey participants in the open-ended responses.

### *Union Station*

All of Union Station's top responses for good/safe areas match the same exact trends for all stations, and excluding the light automobile traffic response, with the top reason being heavy pedestrian traffic (41.1%). The number one reason that people reported areas to be bad or unsafe for walking was the number of transients or homeless in the area (26.7%). Other responses follow that of the general trends, whereby heavy traffic noted in 21.4% of responses, night versus day safety 14.3%, and bad lighting at 10.7%. All of these bad and unsafe responses for Union Station are in line with the

TOD's actual statistics and distribution of both crime and traffic accidents involving pedestrians or cyclists (see Figure 6 and Figure 7 in Chapter Three for the frequency of crime and traffic, respectively, as well as Appendix A for the hotspot density map). Specifically, Union Station ranks the highest relative to all other stations in terms of the total frequency of traffic accidents involving pedestrians and cyclists, which is reflective of the second highest open ended response for bad/unsafe areas. Additionally, the high rates of transients, night versus day safety, and lighting are reflective of the stations high crime rates, whereby it ranked the second highest across all four station sites, and just under 27<sup>th</sup> and Welton's crime rate.

#### *27<sup>th</sup> and Welton*

As with other stations, 27<sup>th</sup> and Welton's top responses for good/safe areas reflect the top responses for all stations. Unique responses, however, are present. For instance, ranked number three, at 13.3% of responses, is the mentioning that all areas on the map are safe for walking. Other unique responses for good/safe areas for 27<sup>th</sup> and Welton include the fact that the area is residential (10%), and interestingly, has lots of families (10%). Another interesting finding was that a few participants mentioned that the area is "not as bad" as public opinion, though this response does not make the top list.

As for bad/unsafe areas, 27<sup>th</sup> and Welton seems to have the most varied, and even contradicting responses. The highest reoccurring response was the homeless and transient population (26.7%), followed by heavier traffic at (16.7%), and bad lighting (13.3%). One of the more interesting contradicting results was related to safety in the area. On one hand, a significant number of people mentioned that none of the 27<sup>th</sup> and Welton TOD is

unsafe (13.3%). At the other end of the spectrum, a significant number of participants mentioned that the area is very unsafe either due to the presence of drug dealers (13.3%), or the fact that these areas have a lot of crime or violence (10%). These findings for 27<sup>th</sup> and Welton's open ended responses for bad/unsafe areas are in line with the TOD's actual statistics of crime and traffic accidents involving pedestrians and cyclists (see Figure 6 and Figure 7 in Chapter Three for crime and traffic frequency tables respectively, as well as Appendix A for the hotspot density maps). For both crime and traffic, 27<sup>th</sup> and Welton scores extremely high compared to the other stations, whereby it scored the highest for crime frequency and the second highest for traffic accidents involving pedestrians or cyclists. These statistics are further supported by the open-ended responses for bad/unsafe areas in 27<sup>th</sup> and Welton and could perhaps provide some explanation as to why 27<sup>th</sup> and Welton received varied, yet mostly negative responses related to automobile traffic and crime rates.

### **Behavioral Responses to Closed-Ended Questions**

Three closed questions on walking behavior were included in the survey—(1) “Do you normally walk to the station?”, (2) “Do you normally walk in the neighborhood?”, and (3) “How often do you normally walk in the neighborhood?” The number and percent of walking behavior responses for the three behavior survey questions are displayed in

Table 14 below. For all three questions, possible responses were grouped into two categories. For both the questions asking participants if they walk to the station or normally walk in the area, responses were grouped into either “yes” or “no/sometimes.”

For the question asking participants how often they walk in the TOD area, responses were grouped into “frequent” and “infrequent” categories, whereby frequent included responses ranging from 3-7 times a week, while infrequent walkers included responses of 2 or fewer times a week. Given the percentages alone, all stations appear to have similar walking behavior responses. One possible reason for this similarity is that it is probably due to a walker response bias, whereby those that walk around the TOD on a regular basis are more likely to fill out a survey about walking than non-walkers. Discussed below are the results for the statistical tests run to assess if there actually is a difference in these closed-ended survey questions on walking behavior.

Table 14: Closed Behavioral Questions, Summary Statistics

		<b>Alameda</b>		<b>Louisiana Pearl</b>		<b>Union Station</b>		<b>27th and Welton</b>	
		<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>	<b>n</b>	<b>%</b>
<b>Walk to Station</b>	Yes	27	75	41	71.9	37	66.1	22	73.3
	Sometimes/No	9	25	16	28.1	19	33.9	7	23.3
<b>Walk in Neighborhood</b>	Yes	27	75	48	84.2	46	82.1	25	83.3
	Sometimes/No	9	25	9	15.8	10	17.9	5	16.7
<b>Frequency of Walking in the Area</b>	Frequent	30	83.3	46	80.7	44	78.6	25	83.3
	Infrequent	6	16.7	11	19.3	12	21.5	5	16.7

*Pearson’s Results for Behavioral Responses across Individual Stations*

As the proportions in Table 14 suggest, all results from the Chi-squared test indicate that there is no statistically significant difference between the closed-question behavioral responses across each station. Therefore, based on the measures of walking frequency (categories of frequently, and infrequently), and whether or not participants indicated that they walk or do not walk (yes or sometimes/no) to the station and within the area, there is no difference in the walking behavior across all four stations. Both the contingency table and resulting statistics can be found in Appendix C.

### Behavioral Responses for Open-Ended Questions

Only one survey question pertained directly to walking behavior—“If you walk to the station, what are your main reasons for not walking?” Unfortunately, this question was not well responded. Out of all 179 surveys for all four stations, only 30% of individuals answered this question. Nevertheless, the top five response themes are detailed in Table 15. From most common to least, individuals reported that biking was their alternative to walking, while other discussed that they did not walk due to distance, weather conditions, nighttime hours, or because it is dangerous to walk.

Table 15: Top 5 Coded Behavioral Responses across All Stations, Ranked by Proportional Weight

Reasons For Not Walking	Rank	Response
	1	Bike
	2	Too Far/Distance
	3	Weather
	4	Dark/Night
	5	Crime/Dangerous

### Participant Recommendations to Improve Station Pedestrian Mobility

The top three results for the most common recommendations for pedestrian improvements are detailed in Table 16. As seen, recommendations for better or more lighting is a common recommendation for all four station sites. Better or more police presence and addressing issues of homelessness is another commonly occurring recommendation, making the top hit list for both Alameda and Union Station. Aside from lighting, Louisiana and Pearl and 27<sup>th</sup> and Welton stations have unique recommendations from the rest of the stations. First, Louisiana Pearl’s most common recommendation was to improve automobile signs and traffic lights to accommodate for pedestrian traffic and calm automobile traffic. Relatedly, its second recommendation was to improve pedestrian

signage and increase secured pedestrian crosswalks for safe roadway crossing. Second, for 27<sup>th</sup> and Welton, the coded results show apparent need to improve the conditions of unmaintained sidewalks, and at the same time, increase business activity in the area in order to get more people out walking around, and ultimately, improve the safety of the area.

**Table 16: Top Three Recommendations for Station Improvements**

<b>Alameda</b>	1. Address Homelessness 2. Better/More Police Presence 3. Better/More Lighting
<b>Louisiana Pearl</b>	1. Better/More Signs and Lights to reduce Automobile Speeds 2. Pedestrian Signs/ More Crosswalks 3. Better/More Lighting
<b>Union Station</b>	1. Better/More Police Presence 2. Address Homelessness 3. Better/More Lighting
<b>27<sup>th</sup> and Welton</b>	1. Better/More Lighting 2. Improve Sidewalk Conditions 3. Increase Businesses in the Area

### **Public Images of Pedestrian Perception of Space and Walking Behavior**

Public images, or composite sketch density maps, were created for all four sketch maps—(1) routes walked to the station, (2) routes walked within a given week, (3) areas perceived to be good or safe for walking, and (4) areas perceived as bad or unsafe for walking. See Appendix D for all station’s composite maps. These composite maps show density based on the number of times individual sketches overlap and are good indicators of commonly held perceptions of space. Because sketching is optional, and because some sketches did not pass the sketch quality control as detailed in Chapter Four, each composite map is composed of a different number of individual sketch maps. Detailed in Table 17 are the number of individual sketches used to generate each of the four

composite maps for the four station study sites. Explored in this section is the general trends of behavior and perception of space for all stations' composite maps.

Table 17: Sketch Map Sample Sizes and Proportions

Station	Sketch Map	Number of Sketches	Number of Surveys	Percent Sketched
<b>Alameda</b>	Good/Safe Area	35	36	97.2%
	Bad/Unsafe Areas	35		97.2%
<b>Louisiana Pearl</b>	Good/Safe Area	55	57	96.5%
	Bad/Unsafe Areas	49		86.0%
<b>Union Station</b>	Good/Safe Area	53	56	94.6%
	Bad/Unsafe Areas	50		89.3%
<b>27th and Welton</b>	Good/Safe Area	27	30	90.0%
	Bad/Unsafe Areas	25		83.3%

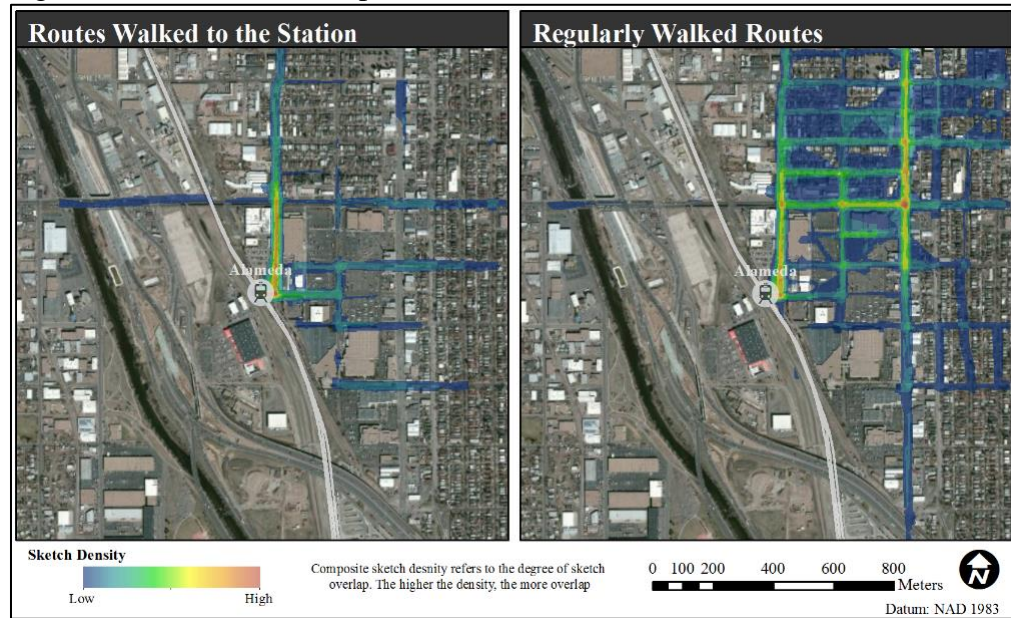
### **Behavior Composites: Routes Walked to the Station and Routes Normally Walked in a Week**

#### *Alameda*

By far, the most commonly walked route to the Alameda station begins at Cherokee and Alameda and extends southward on Cherokee until reaching the station. With a few exceptions, most of the walkers walking to the station walk about a quarter mile stretch, well within the ½ mile walkshed.

Routes normally walked within a given week for the Alameda survey participants shows a slightly different story than the routes walked to the station composite map. In addition to displaying a high density walking activity on Cherokee south of the Cherokee and Alameda intersection, there is a considerable amount of activity taking place along South Broadway, extending up the stretch of businesses north of Dakota Avenue. Interestingly, these routes largely exist outside of the Alameda ½ mile walkshed.

Figure 10: Behavioral Composites—Alameda



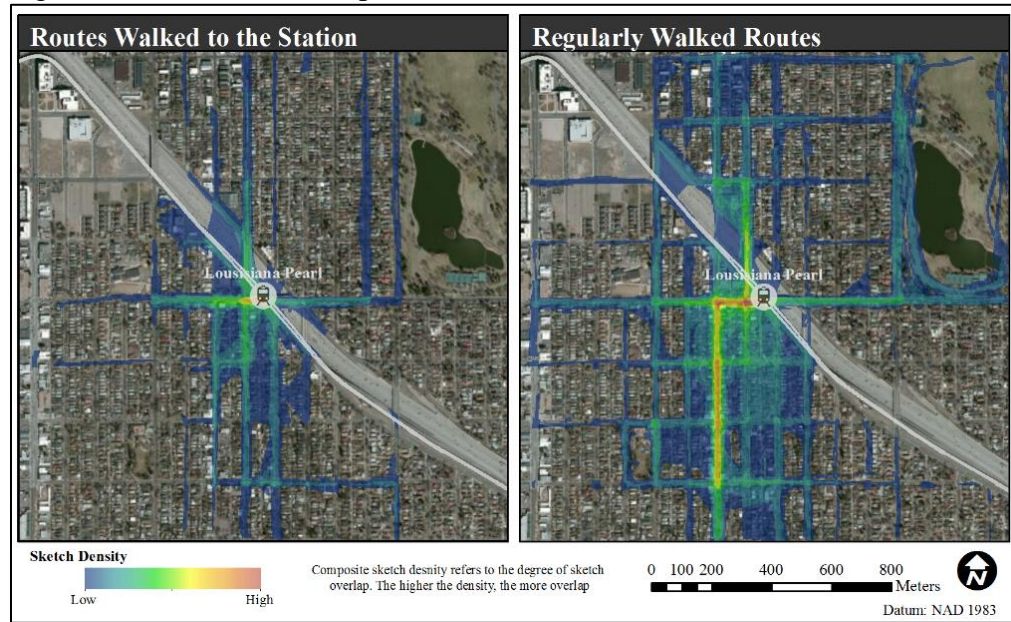
### *Louisiana Pearl*

Practically most of the routes walked to the station, as indicated by the station's composite map, indicate that the majority of those walking to the Louisiana Pearl light rail station are coming from destinations within the half mile walkshed. Most densely sketched routes create a set of crosshairs centered at the station, whereby the major legs are Pearl and Louisiana.

The sketch composite maps of commonly walked routes within the Louisiana Pearl neighborhood makes for an interesting analysis. As shown in the composite, there is a dense network of streets and paths that are commonly walked, taking up majority of the possible routes to walk within the area. Interestingly, there is a very strong density along the South Pearl businesses district as well as north of the Station along Pearl and extending north east out of the walkshed boundaries toward Washington Park.



Figure 11: Behavioral Composites—Louisiana Pearl

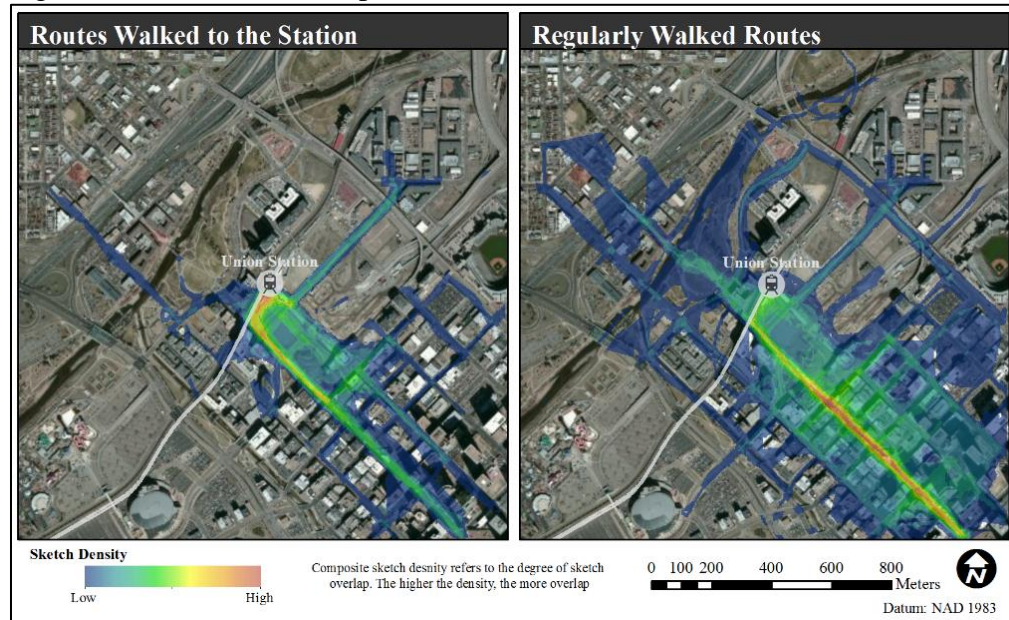


### *Union Station*

For Union Station, the most commonly walked route to the station is along 16<sup>th</sup> Street Mall. Also, a particularly interesting function of this map is that with the exception of a few routes, majority of the people are coming from the same area, south east of the station.

Commonly walked routes within the Union Station TOD area include the 16<sup>th</sup> Street Mall area, with the highest density along 16<sup>th</sup> street, and moderate density along the paths extending both east and west of 16<sup>th</sup> street, creating a buffer-like area around the Mall.

Figure 12: Behavioral Composites—Union Station



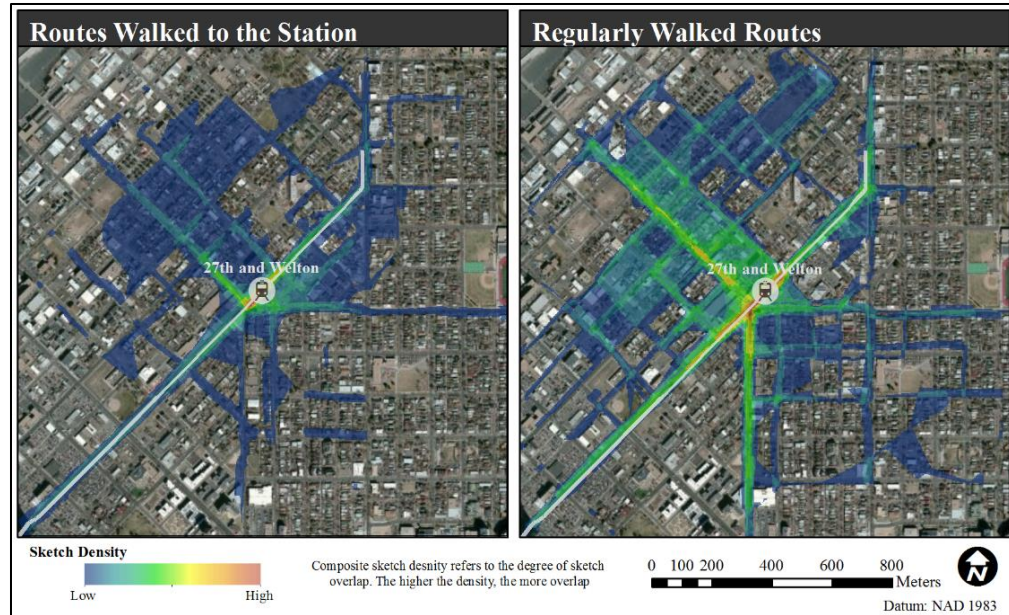
### *27th and Welton*

The most commonly walked routes to the station extend just 1-2 blocks northeast of the station along Welton Ave and about 2 blocks north west on 27<sup>th</sup> St. For the most part, most common routes (i.e. routes walked by more than 1 person) are within a very small radius of the 27<sup>th</sup> and Welton Station, and practically all routes are within the half-mile TOD walkshed.

Perhaps reflective of the historic neighborhood name, regularly walked routes within the 27<sup>th</sup> and Welton neighborhood create a 5-point star extending outward along Welton Ave, Washington St, 26<sup>th</sup> St, and 27<sup>th</sup> St. Though not as extensive as Louisiana, 27<sup>th</sup> and Welton's composite map of regularly walked routes are reflective of the walkshed size, whereby more routes extend outward encompassing a large network of streets and pedestrian-only paths. Additionally, similar to the routes walked to the station,

most routes regularly walked by participants of this survey lie within the bounds of the half-mile TOD.

Figure 13: Behavioral Composites—27<sup>th</sup> and Welton



### Perception Composites: Good/Safe Areas and Bad/Unsafe Areas for Walking

#### *Trends across all stations*

Though the composite maps are by nature unique to the individual TOD geography, there is one particular aspect related to perception of space that is similar across all stations. Namely, the most densely agreed areas for good/safe and bad/unsafe walking are located along corridors. Therefore, this suggests that people commonly perceive specific streets and paths, rather than generalized areas, when forming conceptions of good or bad pedestrian space.

#### *Alameda*

Majority of the agreement for good/safe areas is north east and east of the station. Areas with the most agreement are those north of Alameda and east of Cherokee, while a

moderate amount of overlap extends southward on Broadway. There is a clear divide east and west of the station, and overall, the good/safe areas are reflective of the walking behavior composites.

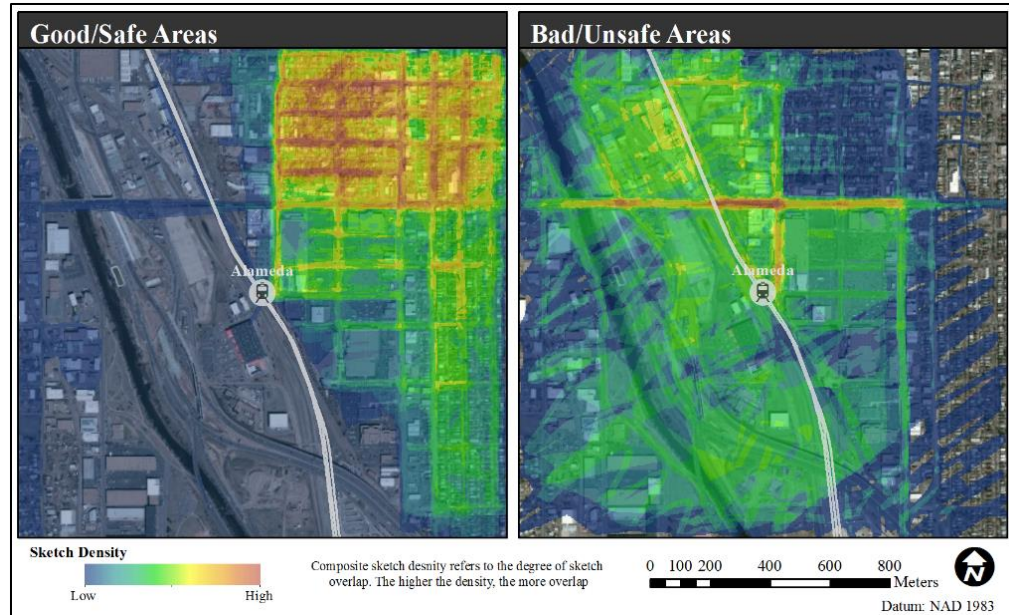
The commonly agreed areas in the Alameda TOD to be bad or unsafe for walking are exactly opposite of the good or safe composite sketch, including a very large section of the TOD and all areas west of the light rail station. The intersection of Alameda and Cherokee makes up the area that is agreed to be the worst by most survey participants. Also, the composites suggest that the Alameda light rail station is a commonly agreed area to be bad or unsafe for pedestrians. This large swatch of bad/unsafe areas shown in the composite map can be further associated with the results presented earlier whereby Alameda was shown to have significantly more people disagree that the area is safe for walking.

Interestingly, when compared to the hotspot maps in Appendix A for density of traffic and crime, the composite map areas most commonly perceived to be good or safe areas for walking match up considerably well with the hotspots for both crime and traffic density. In fact, they almost mirror one another. At the same time, the areas most commonly perceived to be bad or unsafe for walking do not match up with crime or traffic hotspots. Essentially, these spatial relationships throw a wrench into the idea that people's perceptual definitions of what constitutes a safe area is based on some rational understanding of both crime and traffic safety—because if there were rational logic to our definitions of safe areas, then the most commonly perceived areas to be good/safe for



walking would not align so perfectly with crime and traffic hotspots as it has shown to do in this research.

Figure 14: Perception Composites—Alameda



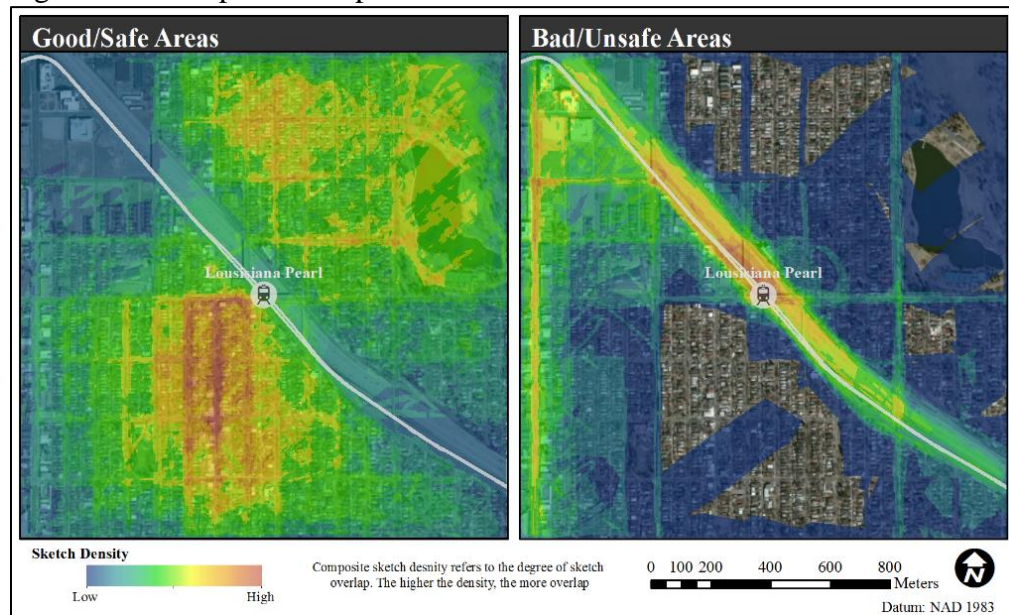
### *Louisiana Pearl*

Compared to all other good/safe sketch composites, Louisiana Pearl’s collective perception of space is by far the largest and the densest, covering majority of the map area and TOD. Indeed, there are two clear groupings on either side of the 1-25 interstate divide and extending outward to the bounds of the half-mile TOD. Interestingly, the highest density occurs along the South Pearl business area. The vast spread of good/safe areas in the composite is reflective in the top open-ended responses where people mentioned that areas are safe or good for walking is due to the presence of light automobile traffic and as well as the fact that the area is a “safe neighborhood.”

For Louisiana Pearl, two major areas seem to be commonly agreed as bad for walking—areas at or along Broadway, and the areas at or along the Interstate (I-25). Both

of these areas are linear and extend along the road network. Compared to the traffic and crime hotspot maps in Appendix A, the composite of bad/unsafe areas aligns relatively well (considering the TOD's low density for both crime and traffic) with the fact that most of the crime and traffic accidents occur along areas directly adjacent to I-25. Interestingly, when related to the open-ended responses for why areas are bad or unsafe for walking, there is a clear relationship with the responses and the sketch areas. Overall, the number one reason people mentioned that areas are bad or unsafe for walking is due to the presence of heavy auto-traffic, and both I-25 areas and Broadway happen to be auto-dominant.

Figure 15: Perception Composites—Louisiana Pearl



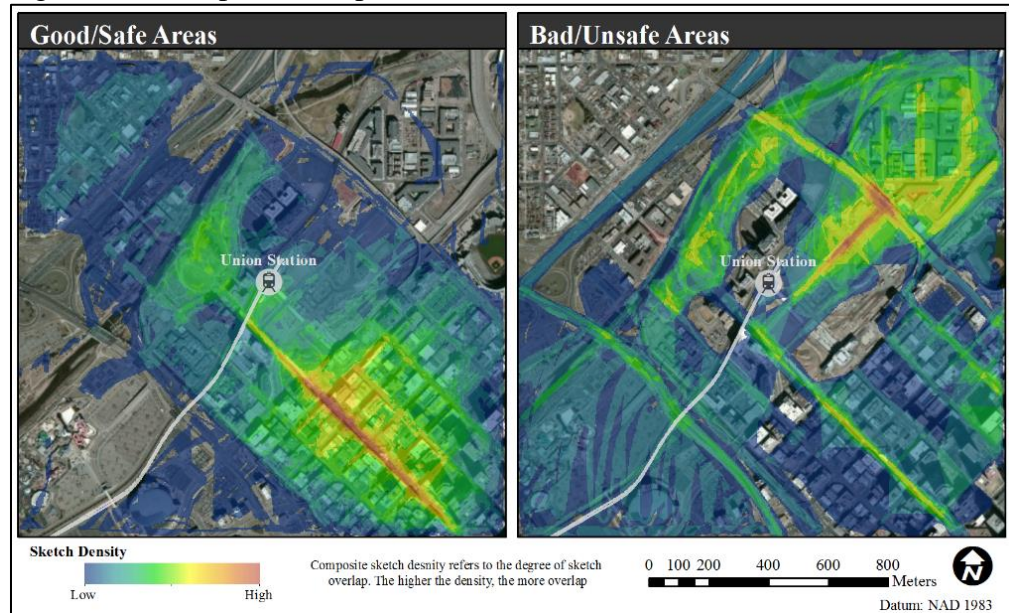
### *Union Station*

Areas commonly agreed to be good for walking include those streets surrounding 16<sup>th</sup> Street, as well as the Confluence Park area just north of the station. Not surprisingly, the highest density for good/safe areas is by far the 16<sup>th</sup> Street Mall area, a pedestrian-

only and commercial outdoor mall. This composite density is reflective of the top five responses across all stations for good/safe areas because the areas most densely sketched (e.g. the 16<sup>th</sup> Street Mall and Union Station multimodal complex) are text-book examples of effective pedestrian design.

For the bad/unsafe areas for walking, Union Station composite map shows the most density along areas with parks (Confluence and City of Cuernavaca Park), and areas north east of the station, particularly north east of 20<sup>th</sup> St near Coors Field. In direct contrast to the commonly agreed good/safe areas for walking, the composite map for Union Station's bad/unsafe areas indicated a considerable amount of overlap along areas also seen as good areas for walking, such as Confluence Park and 16<sup>th</sup> Street Mall. These two areas are also noticeable in the crime and traffic hotspot maps in Appendix A, whereby, both Confluence Park and 16<sup>th</sup> Street Mall have high densities of crime rates, and areas directly buffering 16<sup>th</sup> Street Mall are shown to also have high rates of traffic accidents involving pedestrians and cyclists. This is an interesting phenomenon because it suggest that good areas for walking are also bad areas for walking, perhaps depending on the time of day.

Figure 16: Perception Composites—Union Station



### *27<sup>th</sup> and Welton*

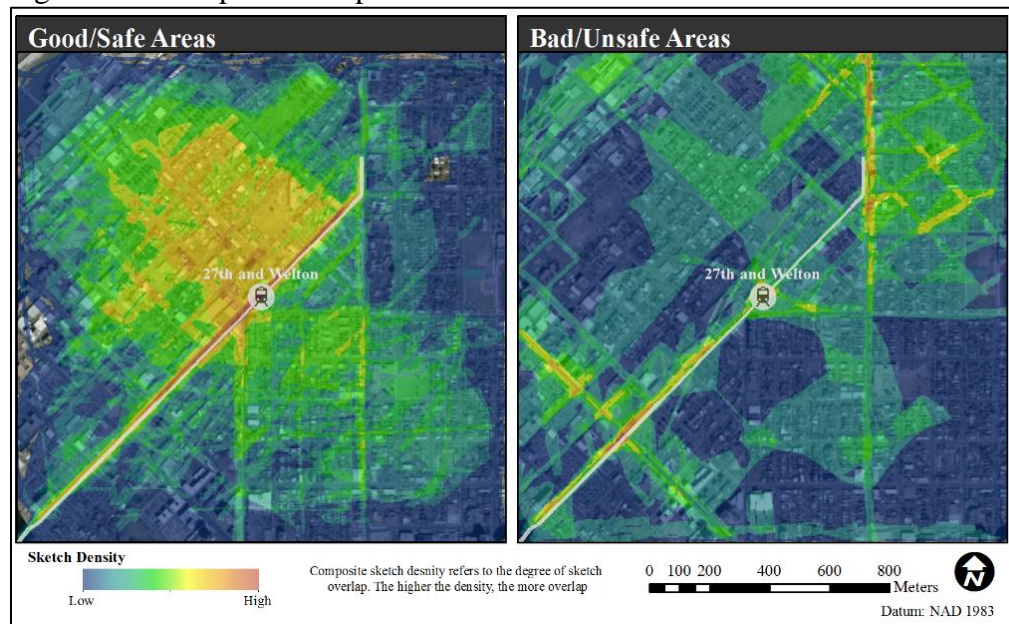
For good or safe areas for walking, the 27<sup>th</sup> and Welton composite map indicates that the most agreed areas are along Welton Street. Additionally, many people perceive the area extending from Walnut to the 27<sup>th</sup> and Welton Station, bounded on either side by 25<sup>th</sup> St and 31<sup>st</sup> St, to be good or safe for walking.

The composite map of bad/unsafe areas for 27<sup>th</sup> and Welton is by far the patchiest density distribution, showing almost no clear spatial pattern of commonly agreed areas that are bad or unsafe for walking. The only patterns that are discernable in this composite map are along pieces of the road network, particularly areas along Downing near the 30<sup>th</sup> and Downing light rail station, as well as the intersection of Welton Street and Park Avenue. These patterns of agreement, however, are not super clear. Overall, the composite shows a spatial mismatch. This spatial mismatch can be further validated when compared with the top open-ended responses for why areas are bad or unsafe for walking.



As mentioned earlier in this chapter, people either said that none of the areas on the map are unsafe for walking, or that the areas are very unsafe due to violent crimes and presence of drug dealers—both of which are completely opposite and contradictory responses. Furthermore, this bad/unsafe area spatial mismatch is also associated with the statistical analysis whereby significantly more 27<sup>th</sup> and Welton participants disagree that area is safe from crime and disagree that the neighborhood is good for walking. Finally, the spatial mismatch is further affirmed when the sketch composites are compared to the hotspot map in Appendix A for both crime and traffic accident densities, whereby the sketch agreement for good areas are somewhat in line with the hotspot area for crime and the density of accidents.

Figure 17: Perception Composites—27<sup>th</sup> and Welton



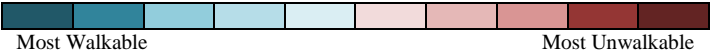
## Spatial Relationships of Geographic Measures of Walkability: General, Distance-Oriented, and Perceived

### *Heat Map Score Chart Comparison*

The results of the heat map score chart are depicted in Figure 18. Given the quantitative values for the spatial measures of walking, each station is assigned a report card like grading. Red color ranges represent unwalkable conditions, with the darkest red being the worst walkability score. Blue colors represent walkable conditions, with the darkest blue representing the best conditions. Ranking from highest score, or most walkable TODs, to the lowest score is as follows: Louisiana Pearl, 27<sup>th</sup> and Welton, Union Station, and Alameda.

Figure 18: Heat Map of Spatial Dimensions

	General	Distance-Oriented	Perceived		
	3D Score	% Walkshed Area	%Good vs Bad Area	Survey Rating Questions	Overall Perception
Alameda	-2.39	32.22	18.3	Somewhat Agree	Acceptable/ Not Good
Louisiana Pearl	0.23	70.15	57.1	Strongly Agree	Very Good
Union Station	-1.16	48.88	15.3	Somewhat Agree	Somewhat Good
27 <sup>th</sup> and Welton	3.32	67.06	44.5 <sup>1</sup>	Somewhat Agree	Acceptable/ Not Good



As shown in the score chart, both Alameda and Union Station score lowest for all three spatial dimensions of walking, and their total aggregated walking score falls within the unwalkable color range. Notice how there is an interesting color patterning between

<sup>1</sup> Part of the reason that 27<sup>th</sup> and Welton received such a high score for percent good versus bad area is because there was little to no sketch agreement of bad/unsafe areas for participants surveyed; while the good/safe areas exhibited a considerable amount of agreement.

the two higher scored TODs and the two lower Score TODs. Louisiana Pearl and 27<sup>th</sup> and Welton score upper-value measures within the blue walkable end of the spectrum.

Whereas, in contrast, both Union Station and Alameda seem to have a distinct polarization of red and blue ends of the walkable-unwalkable spectrum. This divide occurs between the physical and perceived space dimensions, where both stations score poorly among the physical space measures, and then relatively well (similar to the other two stations) for the first two measures of perceived space. The polarization is not too extreme, however, it is still discernable and worth noting. When the open ended question pertaining to overall perception of space is factored into the equation, Alameda's results reflect the physical space measures, however, Union Station's results enhance the physical-perceived space polarity. In sharp contrast, 27<sup>th</sup> and Welton scores highly on all measures of walkability, except for the open-ended question pertaining to individuals' overall perceptions of the TOD for walking. It is hard to say whether or not the percent good versus bad calculation is a viable statistic for this station because the score might be misleading, particularly for 27<sup>th</sup> and Welton. Though it looks like majority of 27<sup>th</sup> and Welton has more "good" area than "bad" areas for walking, the lack of overall agreement across 27<sup>th</sup> and Welton survey participants about what areas are "bad" is likely the causal reason for 27<sup>th</sup> and Welton receiving such a high score here. With the percent good versus bad calculation aside, this overall perception outlier, as seen in the physical space side for both Alameda and 27<sup>th</sup> and Welton suggests two things. First, despite the fact that 27<sup>th</sup> and Welton scores well on physical metrics of walking, there is a great deal of variation in people's perceptions of walking in the area, and many of these perceptions

lean toward more negative perceptions of safety and accessibility than the physical space metrics might suggest. Second, when given both a rating and open-ended type questions, people might have a tendency to rate positively in regards to the comments they make. With that said, however, the difference between the rating and the open-ended responses could be an outcome of survey-design. The rating questions from strongly-agree to strong-disagree were presented to participants on the first page of the survey, then followed by the sketch maps and open-ended questions on subsequent pages. Indeed, once presented with a mapping exercise, people's memories and geographic awareness might trigger more personally reflective responses related to their perceptions of walking through space.

For all three dimensions, Alameda has the worst pedestrian conditions—it has the smallest walkshed, the worst 3D Walk Score (based on population density, street connectivity, and land use diversity), and one of the lowest differences between percent area of commonly agreed good/safe and bad/unsafe areas as well as overall perception responses. Union Station has the second worst pedestrian conditions, according to the spatial measure calculations, with a walkshed of just less than half of the TOD area, the lowest percent area difference between composite maps' commonly agreed good and bad areas, and a 3D score lower than the population mean for a normal walking neighborhood (due to lower numbers of intersections and population density). However, in terms of physical space, Union Station scores well on the walkability spectrum and with one of the highest overall perception responses. Both 27<sup>th</sup> and Welton and Louisiana Pearl average with a similarly high score across most spatial measures of walking, with differences in

3D scores, due largely to Welton's high population density, and differences in median ranks from the survey's perceived questions, where Louisiana Pearl had more strong agreement. Because of Louisiana Pearl's survey participants show to have a better perception of the walking space than 27<sup>th</sup> and Welton's participants on account of all three measures of perceived space (composite sketch difference between percent commonly agreed good and bad areas, common response for overall perception, and median rank of rating-based survey questions), Louisiana Pearl scores just slightly better than 27<sup>th</sup> and Welton in terms of spatial measures of walkability.

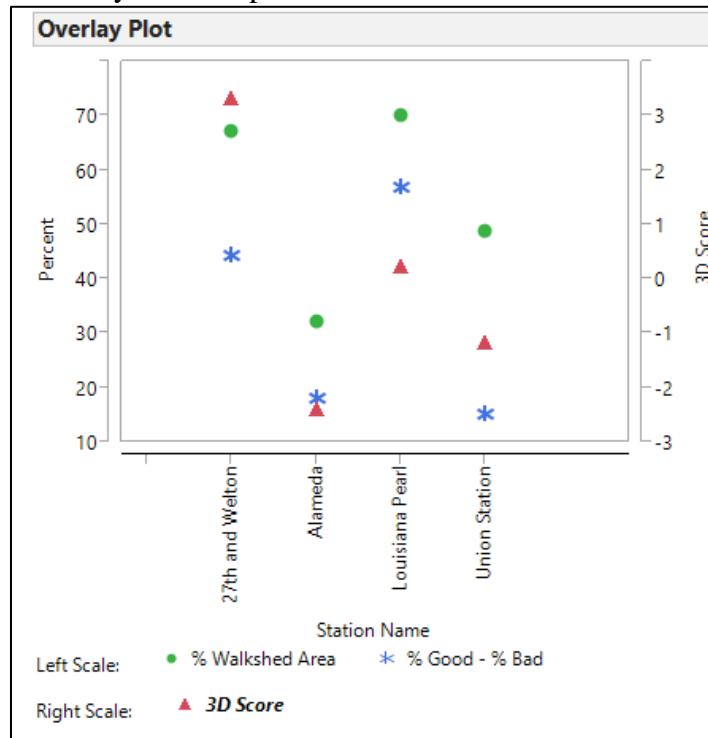
#### *Comparative Plot Distributions*

Distribution plots of the three dimensions of walkability show the same trends of the data with a slightly different perspective. In total, 3 bubble graphs were created in order to show the relative relationships between the three spatial dimensions of walkability, see Appendix C. The first bubble graph created shows the 3D walk score of each station sized by the percent area of walkshed. Using this graph, we can compare and determine that there appears to be a few significant relationships at play. First, this graph, which compares only the four station study sites, practically mirrors the resulting evidence from this research's preliminary analysis which used all current RTD stations, except those residing in Jefferson County. The preliminary analysis, discussed in detail in Chapter Three, tested the correlation between walkshed size and 3D walk score using the non-parametric Spearman's Rank, concluding that a correlation value of 0.8338 was statistically significant evidence to suggest that there is a relationship between walkshed area and 3D scores, where TODs with higher 3D scores have higher walkshed areas.

Second, the bubble plot of 3D walk scores and the perception measure indicates that there is a similar relationship between the 3D walk scores and the difference in perception of good/unsafe and bad/safe areas as there is to that of 3D walk scores and walkshed size, whereby higher 3D scores tend to have more perception agreement and that the TOD area has more good areas for walking than bad areas for walking. Third, the bubble plot with walkshed area and perceived measures somewhat shows that larger communal agreements that there are more good areas than bad areas for walking does appear to correspond with the largest walkshed areas, though this relationship does not appear to be strong.

The overlay plot in Figure 19 depicts all three spatial dimensions of walking, using on the geographic layers—3D walk score, percent walkshed area, and percent good versus bad area—overlaid on top of each other. This overlay plot represents the 3D walk score and percent ranges as separate left and right y-axes, respectively. As depicted, 27<sup>th</sup> and Welton and Louisiana and Pearl rank at the upper end of the plot. Interestingly, Louisiana and Pearl has less variation among the different spatial measures, whereas 27<sup>th</sup> and Welton has more variability, especially among the perceived and physical space attributes, whereby the perceived space (%good minus bad) ranks lower on the scale than Louisiana and Pearl, but still higher relative to the other two stations. Similarly, Union Station has more variability between the walkshed area, ranking higher relative to its ranks of general and perceived walking space. Alameda, on the other hand, consistently ranks low for all three spatial measures.

Figure 19: Overlay Plot of Spatial Dimensions



## Spatial Trends in Walking Behavior and Perception

### Relationships between Behavior and Perceived Space

#### *Chi-Squared Test for Relationship between Closed-Question Behavior and Perception Answers*

Results from the Pearson's Chi-squared test for the relationship between behavior and perception survey questions across all four stations indicate that those that walk to the station and walk in the area agree that they 1) feel capable of walking in the area with ease, 2) that they feel safe from crime, 3) that the neighborhood is great for walking, and 4) that walking is the fastest mode to get around the area. There was no evidence to suggest that those that walk and do not walk to the station or in the neighborhood differed in their agreement about feeling safe from traffic while walking in the area. Additionally, those that frequently walk to the station (three or more times a week) are more likely than

infrequent walkers (two or fewer times a week) to agree that they 1) feel safe from crime while walking in the area, 2) that they think the neighborhood is great for walking, and 3) that they think walking is the fastest way to get around. For each of the tests for the relationship between behavior and perception variables, both the contingency tables and statistical results can be found in Appendix C.

### **Perceived and Behavioral Sketch Map Compatibility**

Based on the composite maps for all stations, there is a clear trend between behavior and perception of space. In particular, the most common routes walked in the neighborhood are located in the areas most commonly agreed to be good or safe for walking. At the same time, few routes, if any, cross the line into the common bad or unsafe areas for walking. This finding is particularly interesting because it denotes a strong relationship between perception of space and walking behavior.

### **Demographic Trends in Behavior and Perception**

#### **Statistical Relationships between Demographics and Perception**

*Closed-Question Answers—Pearson Chi-Squared Test for relationship between demographic and perception Results for All Stations*

Results from the Pearson's Chi-squared test for the relationship between demographics and perception survey questions across all stations indicate that there are significant relationships between all gender groups and perception survey questions. First, those in moderate income groups (50-90k), as opposed to those in the lower income and higher income ranges, are more likely to agree that they feel capable of walking in the neighborhood with ease. Second, there is a significant relationship between gender and feelings of safety from crime and perceptions that walking is the fastest way to get



around the TOD area. For instance, females are much more likely than males to disagree that they feel safe while walking in the area, therefore, females are more likely to harness feelings of unsafety. Additionally, males are much more likely than females to disagree that walking is the fastest mode of travel in the surrounding TOD area. Third, there appears to be a significant racial relationship in regards to thinking that the neighborhood is great for walking. Specifically, Caucasians are much more likely to perceive the TOD as great for walking, while other racial groups are much less likely than Caucasians to think so. Finally, results show that there is statistically significant evidence to suggest that there is a relationship to thinking walking is the fastest mode and to one's geographic relationship to the TOD area (e.g. if they work or live in the TOD area). Those that live-only within the TOD area are more likely to disagree that walking is the fastest way to get around, while those that work-only are more likely to agree. And perhaps not surprisingly, those that neither live nor work within the TOD area are much less likely, compared to all other individuals, to disagree that walking is the fastest way to get around the area. Both the contingency tables and statistical results for each of the tests for the relationship between demographics and behavior variables can be found in Appendix C.

### **Statistical Relationships between Demographics and Behavior**

#### *Closed-Question Answers—Pearson Chi-Squared Test Results for Relationship among Demographics and Behavior All Stations*

Results from the Pearson's Chi-squared test for the relationship between demographics and walking behavior survey questions across all stations indicate that there is no significant evidence to suggest that there are relationships between race, income, gender, or age in terms of walking behavior, however, there are significant

relationships between walking behavior and whether or not someone lives or works within the TOD. More specifically, frequency of walking in the area, and walking or not walking to the station and within the area are all influenced by whether or not someone lives or works within the TOD area. Answer choices of “yes”, “no”, or “sometimes” for questions asking participants if they walked to the station or walked to the area were subdivided into two main categories for the Chi-squared analysis—frequent (“yes”) and infrequent walkers (“no” and “sometimes”). Answer choices (“5-7 times a week”, “3-4 times a week”, “1-2 times a week”, “A few times a month”, “Once a month” and “Rarely Ever”) for the survey question pertaining to how often individuals walk in the area were also divided into two categories of frequent (3-7 times a week) and infrequent walkers (less than 2 times a week). For how often one walks within the area, people who indicated that they both live and work within the TOD all fell within the frequent walker category, while those who neither live nor work within the TOD were more likely to indicate that they infrequently walk in the area, if at all. Interestingly, those who only live within the TOD were just as likely to be frequent or infrequently walkers based on the number of times they indicated walking in the area. Results from this contingency analysis of whether or not someone walks to the station and walks within the neighborhood also show that those that both live and work within the TOD were much more likely to walk to the station, while those that neither live nor work within the TOD were much more likely to not walk to the station or not walk in the area. Also, those that work in the TOD were much less likely to walk within the TOD area than other groups, however they were just as likely to walk to the station (from work) as those that live

within the TOD. Both the contingency tables and statistical results for each of the tests for the relationship between demographics and behavior variables can be found in the Appendix C.

### **Demographic Differences in Composite Distributions**

#### *Perceived Space Composite and Behavior Composite*

All four stations that had demographic composites which appeared to have different spatial distributions for good/safe and bad/unsafe maps, however, 27<sup>th</sup> and Welton by far exhibited the most visual difference in the composites. Based on the demographic sketch composites that looked different from other demographic groups, sign tests were computed to determine if there is a significant difference between the sketch distributions of different demographic groups. In total, all of 27<sup>th</sup> and Welton's demographic groups (race, income, age, and gender) were tested for differences in distributions across groups for the two perception of space maps (both good/safe and bad/unsafe maps). Unlike 27<sup>th</sup> and Welton, which exhibited visual differences in demographic composites for both good/safe and bad/unsafe composites, all other stations only showed to have differences in perception of bad/unsafe areas among certain demographic groups. Race and income groups were compared for Union Station, only race was compared for Louisiana and Pearl, and only age group was compared amongst each other for Alameda.

Results from the sign test for the difference in demographic composites lend itself to interesting results, see Appendix C for the test-statistics. For instance, compared to all other stations, 27<sup>th</sup> and Welton has by far the most difference across demographic groups

among both perception of good/safe areas and bad/unsafe areas. Indeed, 27<sup>th</sup> and Welton exhibited significant results for differences among perceptions of good/safe areas for all demographic variables tests. Likewise, the sign test results show that 27<sup>th</sup> and Welton also has significant results for bad/unsafe areas for all groups except between racial groups (Caucasian and non-Caucasian). It is important to note that the age group of individuals 51 years old or older was excluded from the age demographic composite difference analysis for 27<sup>th</sup> and Welton station due to low numbers of individual sketches that make up the total composite density.

All other tests run for all other stations also resulted in significant differences between demographic groups bad/unsafe composite distributions—for Alameda, there is a difference in perception of bad/unsafe areas among those belonging to the three age groups, there is a significant difference in income and perception of bad/unsafe areas for union station, and finally, there is a significant difference in perception of bad/unsafe areas of Louisiana Pearl among Caucasian and non-Caucasian sub groups.

## **Chapter Seven: Discussion**

The results of this research illustrate the importance of hybrid geographies in mobility research. Indeed, with such a research approach, many conclusions can be gathered to help inform robust pedestrian planning. Given that there are countless conclusions that could be generated here, five major conclusions stand out. First, the relationship between perception and space is complex. Second, physical space measures of walkability play a necessary yet insufficient role in walking behavior. Third, perception plays a key role in walking behavior. Fourth, sketch mapping is a powerful method for pedestrian mobility research. Lastly, though there are many station-specific opportunities to improve pedestrian mobility at each site, on the whole, the most vital improvements to increase pedestrian mobility are related to improving pedestrians' perceptions of space.

### **The Relationship between Perception and Space is Complex**

The results suggest that there is indeed a relationship between perception and physical space, however, this relationship is extremely complex and multi-faceted. When looking at the overlay plot, there is a trend whereby a station's perceived space (percent good area versus percent bad area) is related to the relative ranking of physical space measures. Indeed, stations that score highest for physical walking measures (3D Score and Percent Walkshed Area) appear to be correlated with how much of the TOD area that

people commonly agree to be good for walking versus the area agreed to be bad for walking. Stations that scored well seem to score well for all physical space measures also tend to score well for perceived measures of walkability, while stations that score poorly in physical space measures score relatively poorly as well in the perceived space measures. The best example of the high-high and low-low scoring of physical and perceived measures is Louisiana Pearl (high-high) and Alameda (low-low). Union Station also suggests that there is a middle ground, whereby stations that neither score well nor poorly in physical measures score similarly for perceived measures.

Despite this connection, open-ended responses related to overall perception of the TOD area indicate that there are always exceptions. Just because on paper a neighborhood scores well for walking measures, these walking measures may not be entirely reflective of people's perceptions of walking in the area. 27<sup>th</sup> and Welton is a prime example of a station that scores at the top of its class in terms of the 3D score and percent walkshed area, however, despite these scores, continued negative responses were found to commonly reoccur in the open-ended answers of overall perceptions of walking in the area and rationales as to why areas are bad/unsafe for walking. Additionally, results from the Chi-squared test for differences in perception across the four stations indicate that Welton had higher proportions of individuals to disagree that the area is safe from walking and disagree that the neighborhood is great for walking. Moreover, 27<sup>th</sup> and Welton is the only station to show a clear spatial mismatch in terms of bad/unsafe areas for walking; thus, indicating an overall disagreement among what areas are bad for walking.

The complexity between space and perception of safety from crime and traffic is another complicating factor. For some stations, there is a clear connection between high frequency of traffic accidents or crime events and the actual perceptions of space. 27<sup>th</sup> and Welton is a good example of a station that received negative overall perceptions of the area in terms of crime and traffic safety which aligns well with its statistics of actual crime and traffic accidents in the TOD area, which is especially high for 27<sup>th</sup> and Welton. For other stations, however, the relationship between actual crime and traffic statistics and perceptions of space is extremely unclear. Take Alameda, for instance, where its good/safe area composite map mirrors the hotspot map of high crime and traffic densities. Similarly, Union Station scored particularly well for the open-ended survey responses about people's overall perception of walking in the area, however, its crime and traffic statistics are among the highest of all stations. Finally, Louisiana Pearl's survey responses indicated that there is a problem with the area being unsafe for walking due to heavy traffic, however, these perceptions are not well supported with the statistics on crime and traffic accidents in this area since the station scores very low for both crime and traffic incidences. These three cases suggest that actual statistical measures of pedestrian safety from crime or traffic may not be the influencing factor for individual's perceptions of safety while walking in the area. In other words, people form perceptions based on something else other than actual real-world statistics, perhaps experiences or feelings of the space. As this research has shown, an area can have high crime and traffic accident rates and yet people can still perceive the area to be safe and great for walking (as in the case of Union Station), or a station can have relatively low crime and traffic accident

rates and still people have negative perceptions of safety in the area (as in the case of Alameda).

For many stations, perceptions of bad areas for walking are contingent on the socio-demographic background of individuals. For instance, females are more likely to feel unsafe in the area while males are much more likely to disagree that walking is the fastest way to get around. A racial aspect exists as well, whereby Caucasians are much more likely to agree that the neighborhood is great for walking, while non-Caucasians are much less likely than Caucasians to think so. Finally, perception is also greatly influenced by individual geographies. In particular, whether or not someone lives or works within the TOD area has a significant impact on their overall perceptions of space. For instance, people that neither live nor work within a TOD area are much less likely to think that walking is the fastest way to get around the area, whereas those that work and both live and work are much more likely to think so.

Another aspect related to the complexity of the relationship between perception and space is that people tend to agree about which areas are good or safe for walking but disagree about what areas are bad or unsafe for walking. This relationship can be found across all demographic groups as well as within demographic groups. Across demographic groups, a smaller percent of most-sketched bad areas was calculated compared to the most sketched good areas for all stations. There is a chance that this lower percent most-sketch bad is due to the fact that less area of the TOD is bad for walking, but more than likely, the result is probably due to the fact that people do not hold the same conceptual definitions for what defines a bad walking area. This lack of



perceptual agreement can be further explored in the context of differences among composite sketch maps for different demographic groups. With the exception of 27<sup>th</sup> and Welton which exhibits a spatial mismatch in both good/safe and bad/unsafe areas, the qualitative GIS results indicate that the only differences in sketch composites across demographic groups lies within the bad/unsafe composite sketch maps. For instance, Alameda exhibited differences in composite distributions of bad/unsafe areas across all three age groups (18-34, 35-50, and 51 plus), Union Station's income group composites showed to have significant differences in distribution of bad/unsafe areas within the TOD area, and results indicate that there is a significant difference in the perception distribution of bad/unsafe areas of the Louisiana-Pearl neighborhood among Caucasian and non-Caucasian sub groups. As for good/unsafe areas, these three stations did not show to have any statistically significant difference in the distributions of good/safe areas. Therefore, based on this evidence of disagreement among composite bad/unsafe area distributions for different demographic groups, coupled with evidence of smaller percent areas most often agreed to be bad/unsafe for walking, these results suggest that perception of space is complicated because people commonly agree about what defines a good/safe area for walking, yet, they disagree about what areas are bad/unsafe for walking.

As for 27<sup>th</sup> and Welton, demographic differences in composite distributions occurred in both good/safe composites and bad/unsafe composites, and across many more demographic groups. For all demographic groups (age, gender, race, and income) there is a significantly different distribution of good/safe areas and the same can be said for the

composite distributions of bad/unsafe areas, except for race. These findings reaffirm the spatial mismatch concept for 27<sup>th</sup> and Welton perceived space.

An additional aspect related to the complexity of perception and space relationships is dealing with the phenomenon that good areas are also bad areas. Unlike the spatial mismatch phenomenon present in most 27<sup>th</sup> and Welton measures of perceived space, this characteristic is related to the fact that spaces are both good and bad, depending on the time of the day. This time of the day response is common throughout all station responses and it is intrinsically related to the top two most reoccurring responses for why areas are good/safe for walking—(1) the number of people walking on the street, and (2) the amount of lighting. Within the composite maps, there is often evidence to suggest that certain areas are commonly identified as being good/safe for walking, and at the same time, being bad/unsafe for walking. These findings are in line with the *Eyes on the Street* or *Public Policing* concepts from Jane Jacobs and many other scholars performing research in the social aspects of urban planning and mobility.

### **Physical Space Measures of Walkability Play a Necessary yet Insufficient Role in Walking Behavior**

Results from the preliminary analysis and from this research indicate that there is evidence to suggest that physical space measures of walkability—particularly 3D score and walkshed area—play a necessary yet insufficient role in walking behavior. First, results from the preliminary analysis (discussed in Chapter Three) indicate that there is a very weak, if any, correlation between the 3D walk score and walkshed area.

Additionally, using the walking behavior data generated in this research, Chi-squared

results indicate that there is no statistical relationship between the station type and the walking behavior—both frequency of walking behavior and whether or not someone walks to the station or walks within the area. Furthermore, Chi-squared results suggest there is no difference in demographics and walking behavior.

Essentially, this finding lends itself to the fact that physical space measures of walkability do not have a deterministic relationship with pedestrian walking behavior. Perhaps the best example of this necessary yet insufficient relationship between physical attributes of space and walking behavior can be seen with the 27<sup>th</sup> and Welton and Louisiana and Pearl stations. As the results from this research indicate, 27<sup>th</sup> and Welton clearly scored the highest on all measures of physical walking space, however, it exhibited by far the least amount of walking activity than any other station. At the same time, the Louisiana Pearl station scored somewhere in the middle for physical space measures, yet far exceeded other stations in terms of the amount and frequency of walking behavior. These results underscore the fact that physical space measures do not have a direct or deterministic relationship with actual walking behavior, and that instead, other measures of walkability, such as perceived space, play a more significant role in walking behavior. With that said, physical space measures, such as population density and land use mix, do play a role in walking behavior, however, this research suggests that there is a threshold in which increasing physical measures, such as density, will not attribute to more walking behavior. Indeed, once an area has reached its threshold, other factors such as perceptions of space play a more vital role in encouraging walking activity.

Though much evidence obtained in this research suggest a weak relationship between physical space measures of walkability and actual walking behavior, given a comparative analysis approach of composite maps, as opposed to statistical testing, there is some evidence to suggest that there is slight relationship between the walkshed boundaries and the routes walked to the station. Specifically speaking, those that walk to the station are more likely to take paths within the ½ mile walkshed, however, a few do extend the ½ mile walkshed. These results are indicative of many distance-oriented studies that suggest that walking will only take place within the boundaries of facilitators and barriers of pedestrian landscape and within a specified distance (Bejleri et al. 2011).

Despite the fact that this study lends itself to little support that the physical space influences walking behavior, the composite density maps point toward other measures of physical space—namely, presence and type of destinations—as being spatially related to common walking paths. Number and type of destinations (e.g. businesses, parks, restaurants, etc.) is often a key metric used to measure the distance-oriented walkability of a place. Though this was not a measurement utilized in this research, existence of destinations seem to be the most identified areas of good/safe for walking as well as with walking behavior (routes walked within a given week). For instance, the composite maps of Union Station, Louisiana and Pearl, and Alameda all indicate a high density of perceived good/safe area agreement and walking behavior along popular destination areas, such as the South Pearl Business District in the Louisiana Pearl neighborhood, the 16th street mall in the Union Station TOD, and the south Broadway business district at the edge of Alameda's TOD. As for 27<sup>th</sup> and Welton, there is a lack of businesses and

destinations within the larger neighborhood, which perhaps could be a factor influencing the spatial mismatch phenomena.

### **Perception Plays a Key Role in Walking Behavior**

Compared to the physical measurements of space, the results of this study propose the idea that perception of space plays a keynote role in actual walking behavior. There are many factors allowing me to suggest such a prominent role of perception in behavior. First, behavior composites are closely related to perception composites, particularly perceptions of good or safe areas for walking. In fact, most walked routes, for both station routes and neighborhood route composites, occur within the commonly agreed area to be good/safe area for walking. Based on these composite spatial relationships, it is clear that people are more inclined to walk in the areas that are commonly perceived to be good or safe for walking and they tend to avoid areas with negative perceptions.

Second, the most densely sketched areas for perceived composites, both good/safe areas and bad/unsafe areas, lie along the streets and pedestrian pathways. Instead of people perceiving an elusive or nebulous geographic area as good or bad for walking, the composite map analysis indicates that people most often perceive corridors when thinking of their pedestrian space. Because walking most often takes place along corridors, what this finding signifies is that pedestrians' perceptions of space are fundamentally related to their actual walking behavior and past experiences rather than generalized top-down conceptions of space at large. In other words, pedestrian perceptions of space are conceptualized on-site and contextualized through bottom-up behavioral processes.

Third, statistical results further highlight this important relationship between perception and behavior. For instance, those that walk in the area and those that walk to the station are more likely to feel capable of walking with ease in the TOD neighborhood, they are more likely to think that the neighborhood is great for walking, and they are more likely to think that walking is the fastest way to get around the area. At the same time, compared to infrequent walkers, those that frequently walk in the neighborhood (3-7 times a week) are more likely to feel safe from crime, think that the neighborhood is great for walking, and think that walking is the fastest way to get around the area.

Fourth, the 27<sup>th</sup> and Welton spatial mismatch characteristic of perceived space is perhaps associated with the low numbers of individuals walking in the area. When handing out the surveys, I spent four times as much time, if not more, on various days of the week and time of day handing out surveys at the 27<sup>th</sup> and Welton station and was still unable to hand out all 100 surveys (the same number as other stations). Eventually, I had to abandon additional attempts to hand out all 100 surveys because I reached a point where I was running into the same people over and over. What these experiences allude is that there is little walking activity along the Welton corridor. This can be further associated with the spatial mismatch seen in 27<sup>th</sup> and Welton perception composites, because, as one of the major findings of this research suggests, people are more likely to perceive an area as good or safe for walking if there are other people walking around. Therefore, the lack of people walking in this area, even at the peak hours of mobility, is a likely candidate for the overall disagreement of Welton composites. In other words, there is a sort of feedback between perception of space and walking behavior, whereby people

are more likely to walk in an area that they perceive to be good for walking, which is ultimately related to the number of people out walking on the street. In essence, the more people on the street, the more likely people will walk, and the more likely people will walk, the more likely people will identify an area as good or safe for walking. For 27<sup>th</sup> and Welton, however, it is clear that the lack of pedestrian activity is contributing to the negative perceptions of quality and safety.

As I just alluded to, this research suggests that the relationship between walking behavior and perception is not causal, but rather, it is reciprocal. Both behavior and perception influence each other. The more people walk, the more likely they are to feel safe walking, and thus, harness positive perceptions of the pedestrian mobility space. On the other side of the coin, the more people harness positive perceptions of pedestrian space, the more likely they are to walk.

### **Sketch Mapping is a Powerful Method for Pedestrian Mobility Research**

As proved in this study, sketch mapping provides a powerful method for pedestrian mobility research. In fact, using such an approach integrates qualitative GIS methods with the more quantitative, or traditional GIS approaches and, as shown, helps to generate a more holistic and representative set of findings related to pedestrian mobility. Essentially, by integrating this qualitative and quantitative GIS approach I have been able to synthesize how pedestrian mobility is contextualized and spatialized. Additionally, this sketch mapping and qualitative GIS approach has been shown to be an effective way to collect data on actual walking behavior (routes) and perception of space. This is important because, in the past, data collection on these aspects of mobility has been

limited at best, especially in terms of the larger sample size that surveying methods provide. Furthermore, sketch mapping has proven to be an effective way to survey people. Not only did people seem to enjoy sketching their individual walking cartographies, as suggested by both the response and sketch rate, the sketching exercise seemed to get people thinking about their relationships with space. Indeed, sketching seems to be a powerful mental workout which stimulates memories and perceptions of space that may be suppressed by traditional or non-spatial surveying methods. Finally, as previously discussed, the relationship between perception and behavior is a bottom-up relationship, whereby when people recall personal perceptions of space, they do so by visualizing past experiences on the road. Because of this bottom-up aspect of pedestrian perceptions of space, sketch mapping is a valuable method for pedestrian mobility research pertaining to perception because it inspires these types of geographically-bound responses.

### **The Most Vital Improvements to Increase Pedestrian Mobility Are Related to Influencing and Improving Pedestrians' Perceptions of Space**

Because this research finds that perception and behavior are most closely related than any other aspect of walking space, I argue that the most important thing that should be done to increase pedestrian mobility at Alameda, Louisiana Pearl, Union Station, and 27<sup>th</sup> and Welton is to make changes that influence and improve pedestrian perceptions of space. More specifically, this research lends to the fact that increasing pedestrian visibility and accessibility would be the most positive way to influence more pedestrian mobility in these TODs. In terms of pedestrian visibility, vital improvements for all



stations include increasing the amount of street lights, and particularly pedestrian-scaled street lights that make the pedestrian more visible. Indeed, street lights are a measure of physical space, and increasing the amount of pedestrian scaled lighting will help to encourage a better relationship between physical and perceived space. Encouraging mixed-use development and destinations around the station is also another important factor that will likely lead to more pedestrian activity throughout the day, and therefore, more positive perceptions of the area being good or safe for walking due to the increased pedestrian traffic. This is particularly important for 27<sup>th</sup> and Welton and Alameda. Increasing visibility by increasing pedestrian-scaled lights throughout the TOD, police foot patrolling, and pedestrian activity will likely take away from the fact that people feel vulnerable to crime as well as to areas with dense homeless populations, which is a common recommendation provided for Alameda and Union Station survey participants. Ultimately, by increasing visibility, we are increasing the perceived accessibility of the TOD for pedestrian mobility. Additionally, in physical terms of increasing accessibility, adding pedestrian bridges and pathways, as well as infill development in vacant TOD areas, would help to increase the overall area that is accessible to the pedestrian, and therefore, improving the perceptions of walking space.

## **Chapter Eight: Conclusion**

This research revealed some important findings that contribute to the current walkability and transport-mobility geography literatures. First, the relationship between perception and space is complex. Second, physical space measures of walkability play a necessary yet insufficient role in walking behavior. Third, perception plays a key role in walking behavior. Fourth, sketch mapping is a powerful method for pedestrian mobility research. Lastly, though there are many station-specific opportunities to improve pedestrian mobility at each site, on the whole, the most important things we can do to increase pedestrian mobility is to influence and improve pedestrians' perceptions of space.

Perception of space is complex and multi-faceted. On the one hand, it is heavily influenced by the socio-demographic backgrounds of individuals and past experiences with space. On a different note, however, it is influenced by physical space, though, there are always exceptions as in the case with 27<sup>th</sup> and Welton. These findings are in line with mobility and transport research because it signifies that both transportation structures (physical space) and individual subjectivities (including experiences and socio-demographic background) are both key factors in individual perception of space, further aiding in its complexity of how perception of space is formed.

One theme that emerged from this research is that walking behavior in TOD areas is not influenced greatly by physical space, particularly the 3-Dimensional aspects of population density, street connectivity, and land use mix. This research does suggest, however, distance-oriented measures of walkability seem to play a greater role in walking behavior. Future research related to space and walking behavior should focus efforts on distance-oriented factors, particularly the influence of specific destinations on pedestrian mobility and route choice.

Perhaps one of the most telling findings of the research is that perception plays a paramount role in walking behavior. This is important and indicative of how space shapes perceptions and behavior. This research suggests that space and subjective experiences both play a key role in shaping perception. As if this does not sound complicated enough, I have found that there is a strong relationship between perception and walking behavior, whereby perception influences walking behavior, and then in turn, walking behavior influences perception. Given all of this, it seems that space indirectly influences walking behavior, via cognitive perception. Therefore, the best thing that planners can do to effectively encourage pedestrian mobility is to try to influence positive perceptions of space for pedestrians. Future research should definitely involve this space-perception-behavior triad a step further and examine the influences over a larger number of study sites. In addition, research should try to indulge in ways to influence positive perceptions of space and increase walking behavior. Because perceptions are generated through bottom-up processes, 3D simulations of perception and behavior changes is a promising future for furthering this type of transport-mobility research.

Furthermore, this research proves that sketch mapping and qualitative GIS are valuable tools for transport-mobility research. Future research using such tools should incorporate web GIS applications to stream-line data collection. Creating a web-based GIS that allows users to anonymously contribute their personal geographies could go a long way in participatory planning practices, aiding in the development of planning-oriented volunteered geographic information. If the City of Denver, for instance, had an interactive sketch mapping application designed specifically for their different community planning meetings, planners would be able to synthesize the information from everyone in a quick and effective way in order to generate a plan that is the most conducive to community's overall mobilities or demanded requirements. At the same time, a cataloging of individual's perceptions of space could aid in a better understanding of how perception influences walking behavior over space and time, ultimately better informing effective non-carbon transportation strategies to increase non-auto mobility.

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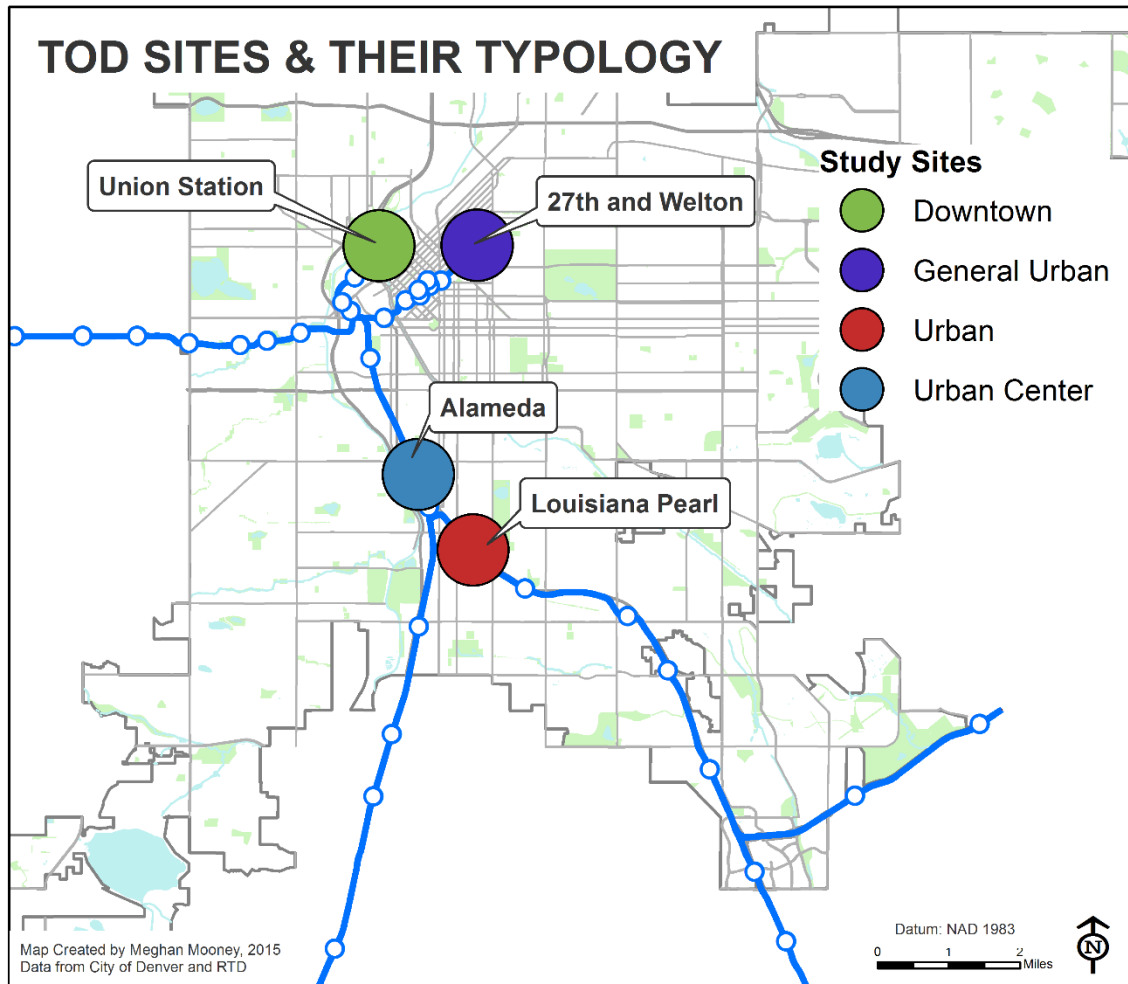
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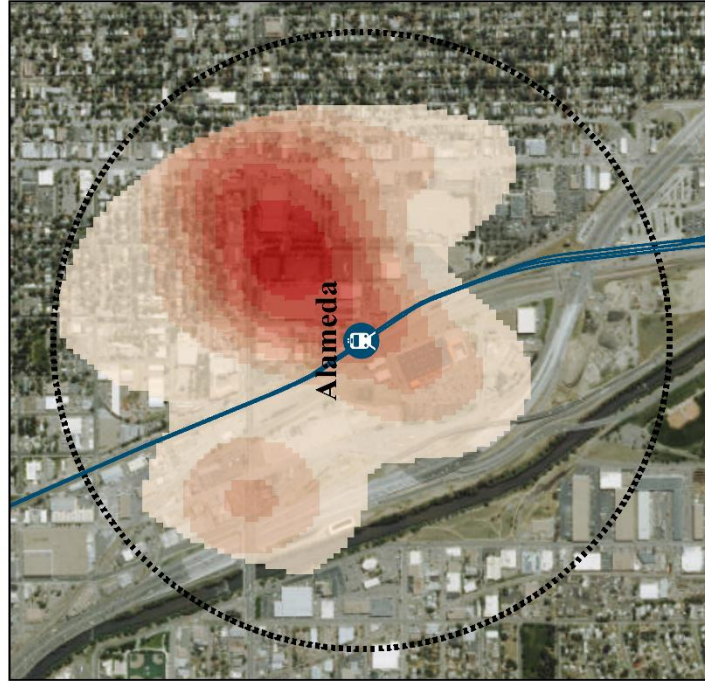
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## Appendix A: Supplementary Maps of TOD Sites

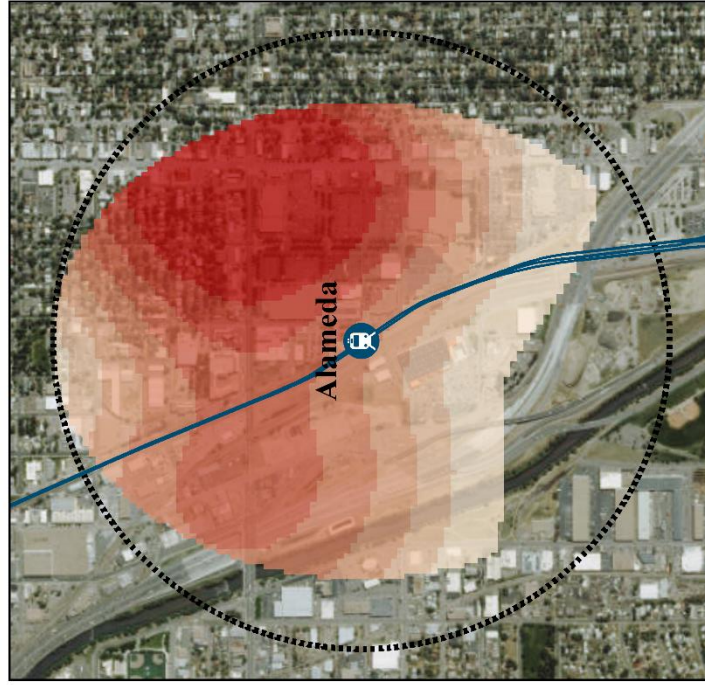


# Alameda Hot Spot Map of Crime Events and Traffic Accidents, 2010-2015

## Crime Events



## Traffic Accidents



Traffic accident hot spots include only those automobile accidents involving pedestrians or cyclists.  
By: Meghan Mooney, 2015  
Data Source: Denver

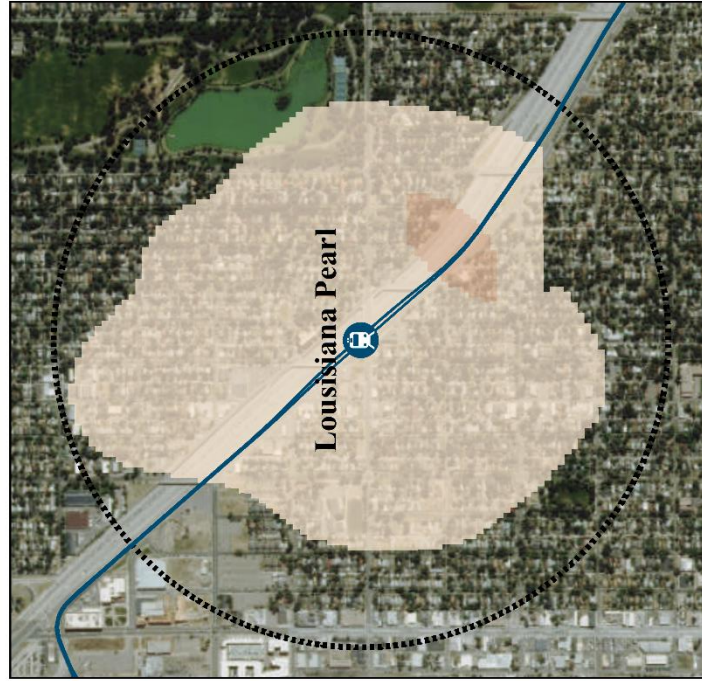
Datum: NAD 1983

0 0.15 0.3 0.6 Miles



# Louisiana Pearl Hot Spot Map of Crime Events and Traffic Accidents, 2010-2015

Crime Events



Traffic Accidents



Traffic accident hot spots include only those automobile accidents involving pedestrians or cyclists.

By: Meghan Mooney, 2015  
Data Source: Denver

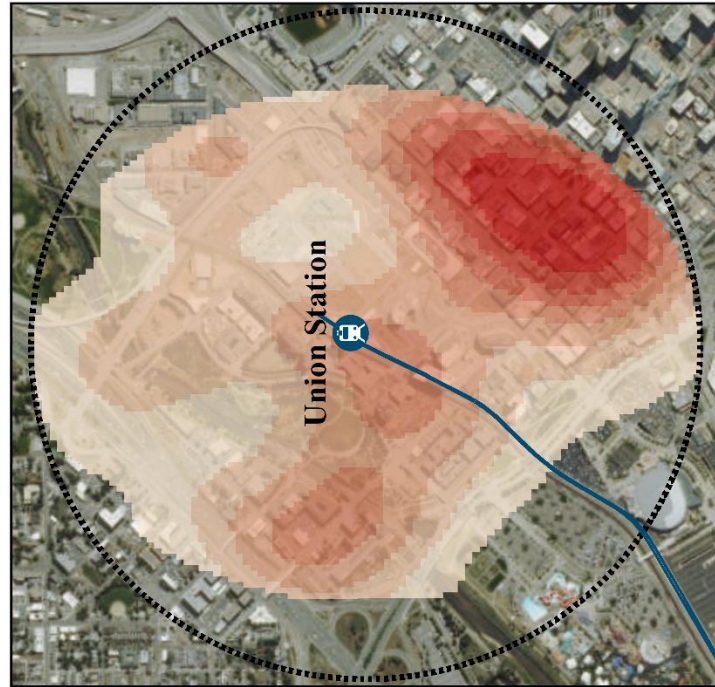
Datum: NAD 1983

0 0.15 0.3 0.6 Miles

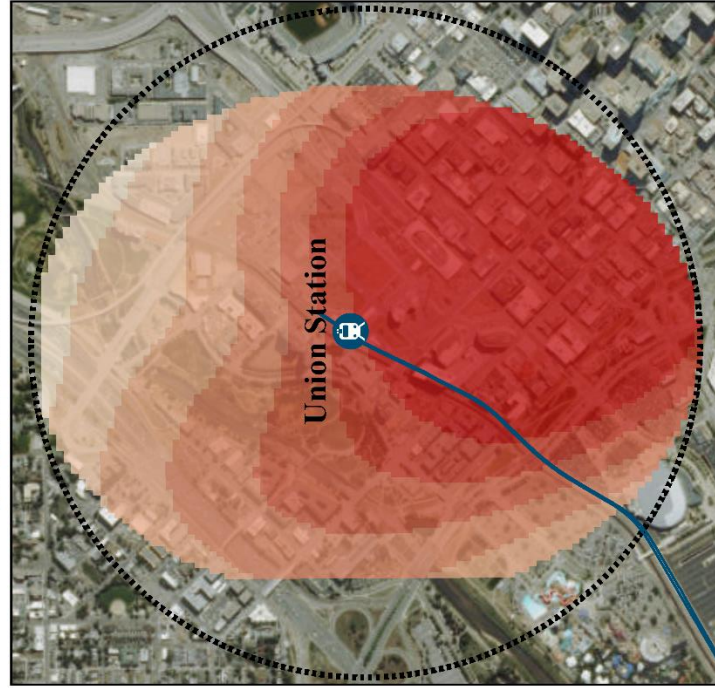


# Union Station Hot Spot Map of Crime Events and Traffic Accidents, 2010-2015

Crime Events



Traffic Accidents



Traffic accident hot spots include only those automobile accidents involving pedestrians or cyclists.

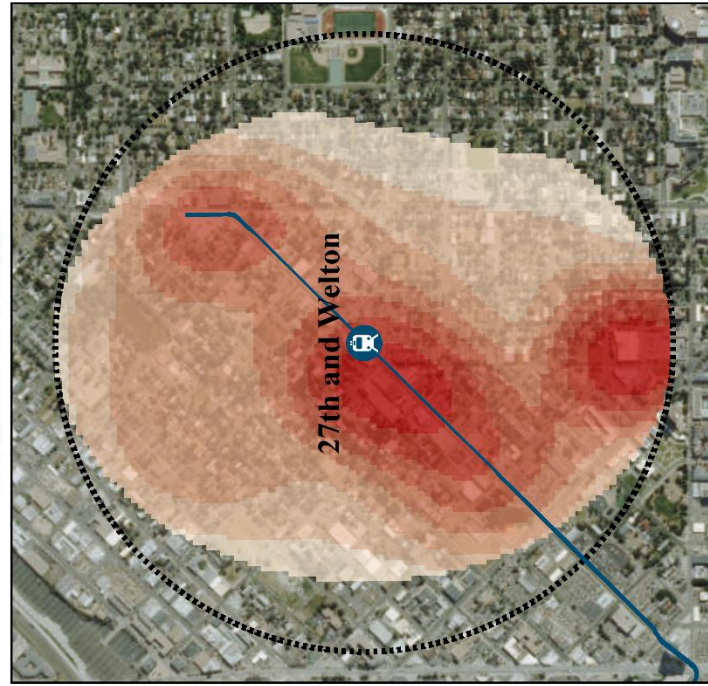
By: Meghan Mooney, 2015  
Data Source: Denver

Datum: NAD 1983

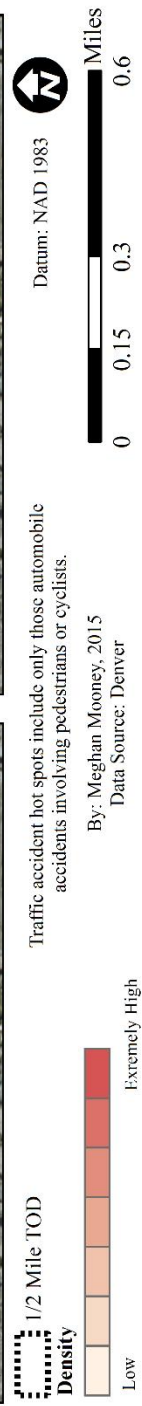
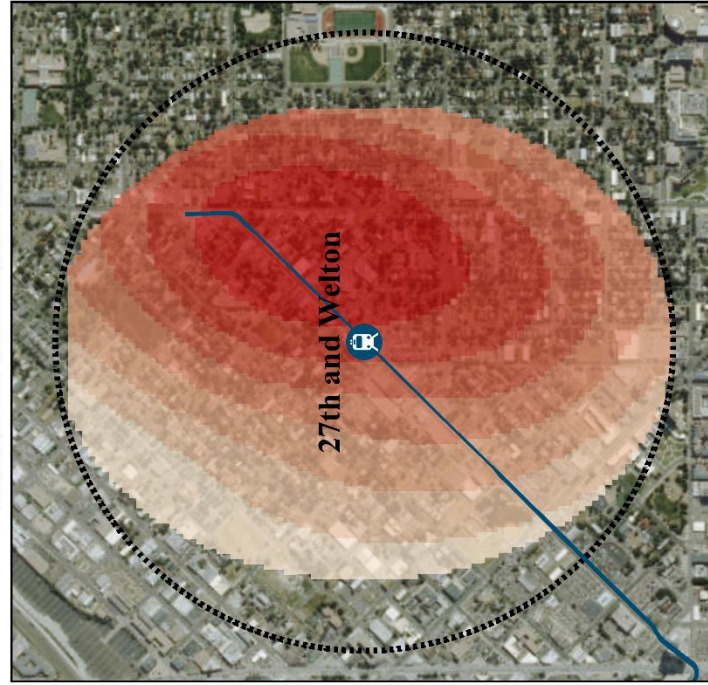
0 0.125 0.25 0.5 Miles

# 27th and Welton Hot Spot Map of Crime Events and Traffic Accidents, 2010-2015

Crime Events



Traffic Accidents



## **Appendix B: Example Survey**

Louisiana Pearl Survey:



### Individual Walking Behavior, Experience, and Perceptions Survey

For this survey, I am interested in your pedestrian behavior and perceptions of walking in the area surrounding the Louisiana-Pearl light rail station (see map to the right).

Using the pencil and highlighter provided, please complete the survey. When you are done, please hand it to one of the surveyors. If you do not finish the survey before the train arrives, please complete the survey on the train and mail it back in the stamped envelope provided.

If you have any questions about the survey or the research, please contact Meghan Mooney at [Meghan.Mooney@du.edu](mailto:Meghan.Mooney@du.edu). Thank you very much for your time.



1. When you use the Louisiana-Pearl light rail station, do you normally walk?

☐ Yes  
☐ No  
☐ Sometimes

2. For any purpose, do you normally walk to get around in this area?

☐ Yes  
☐ No  
☐ Sometimes

3. How often would you say you walk to get around in this area?

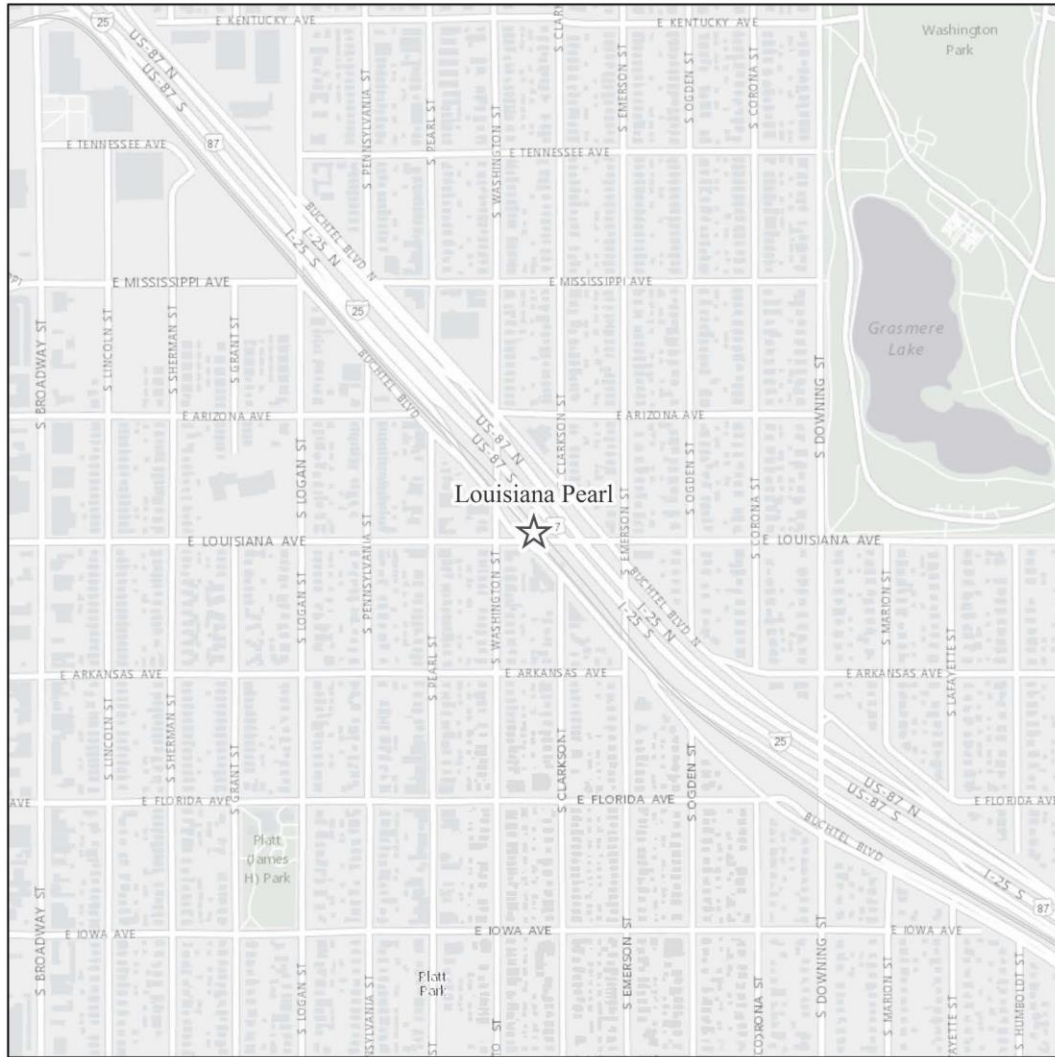
☐ 1-2 times a week  
☐ 3-4 times a week  
☐ 5-7 times a week  
☐ A few times a month  
☐ Once a month  
☐ Rarely ever

4. For the statement below, please mark how strongly you agree or disagree with it.

Statement	Strongly Agree	Somewhat Agree	Somewhat Disagree	Strongly Disagree
a. I am capable of walking in this area with ease	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. I normally feel safe from traffic when walking in this area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. I normally feel safe from crime when walking in this area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. I think this neighborhood is great for walking	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h. I feel that walking is the fastest way for me to get around this area.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

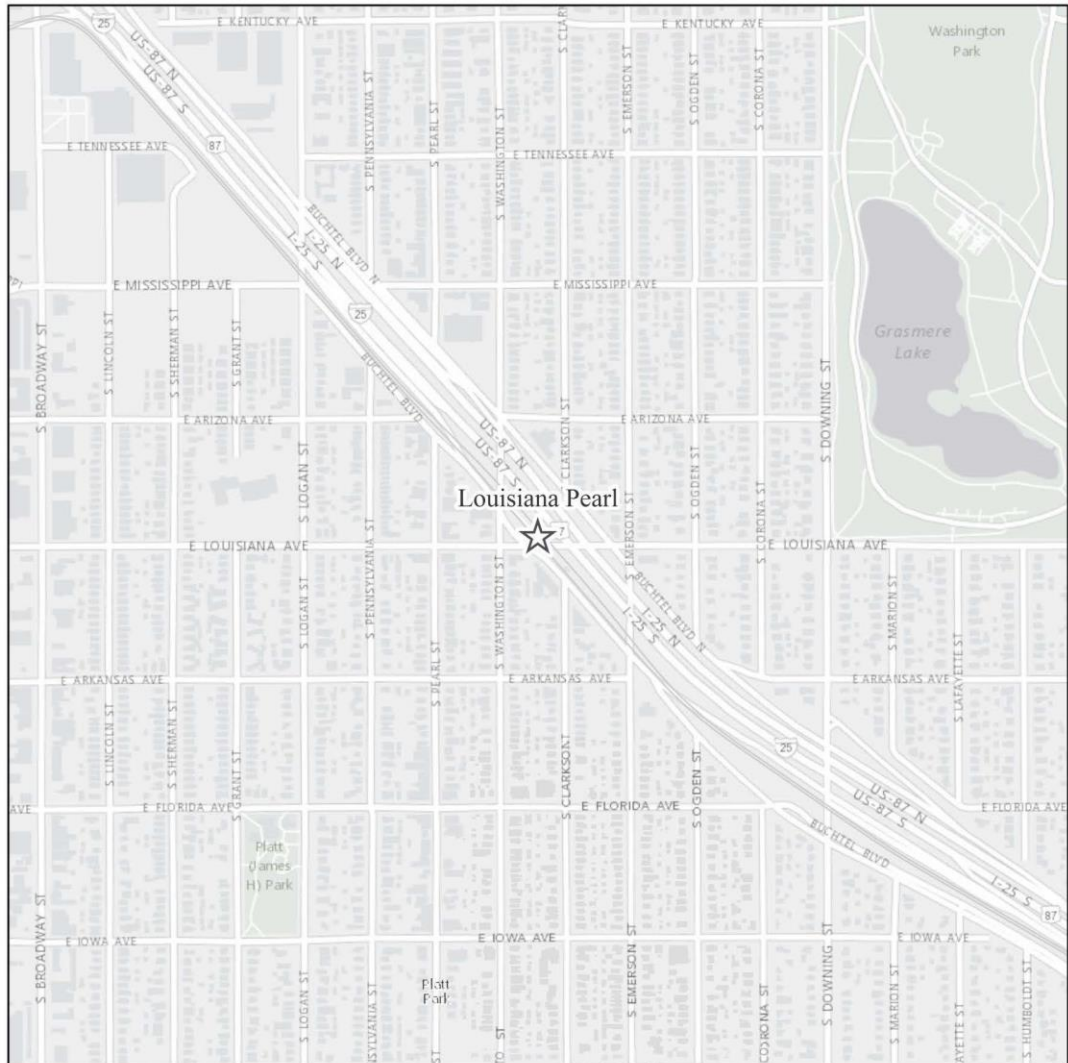
5. If you do not walk in this area, what are your main reasons for not walking?
  
6. Using the **pink highlighter** for **Map 1** below, please trace the route(s), if any, that you normally take to the station, being as specific as possible about your origin.

**MAP 1**



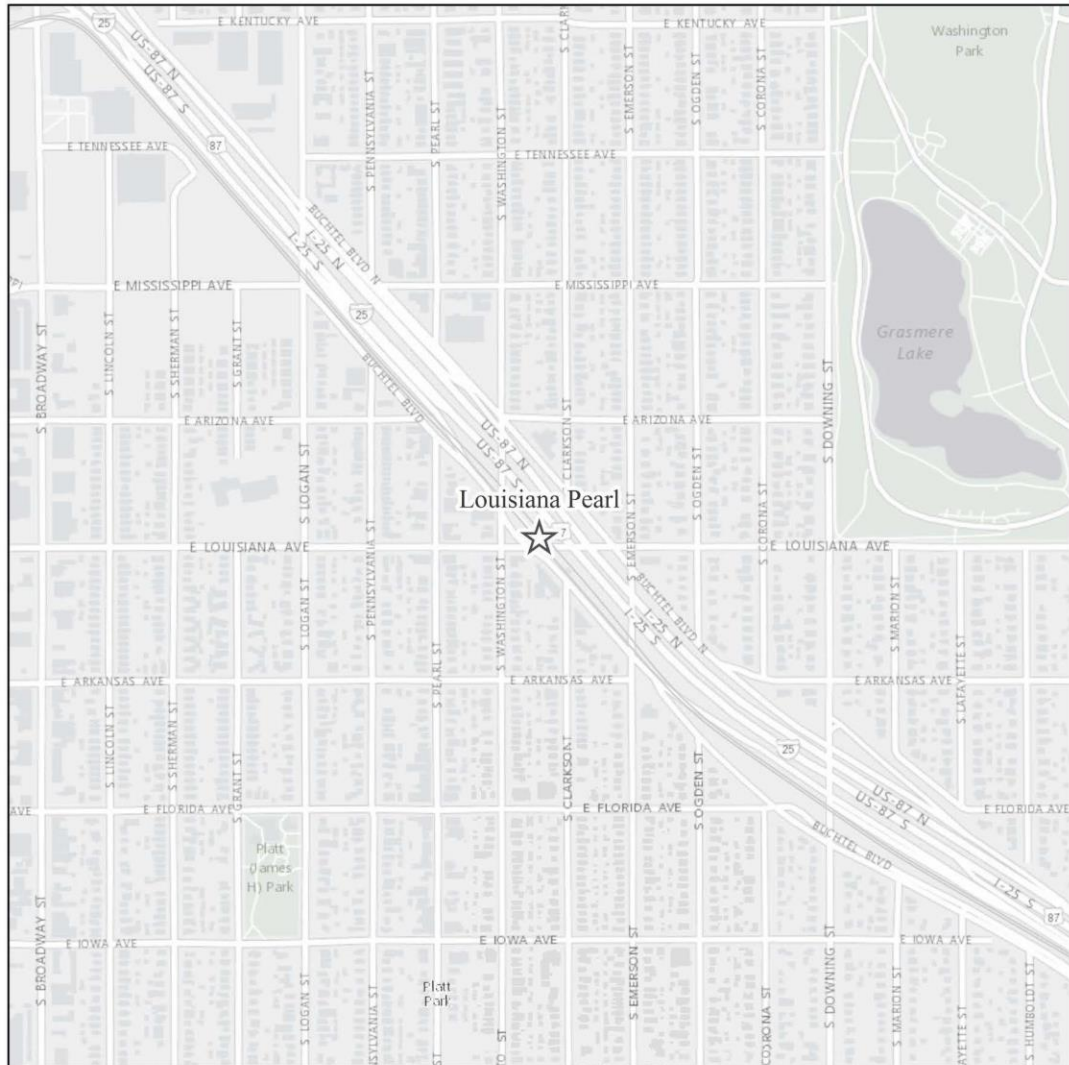
7. Using the ***pink highlighter*** for **Map 2** below, please trace the routes, if any, that you normally walk within a given week for any purpose.

**MAP 2**



8. Using the **pink highlighter** for **Map 3** below, please shade in the area(s) on the map, if any, that you feel are safe or good for walking.

**MAP 3**



## Appendix C: Statistical Results

### B.1: Difference in Population Proportion Results for Survey Sample and Neighborhood Demographics

Alameda				
	Demographic	Z-score	p-value	Reject/Fail to Reject
Gender	Female	1.5356	0.12356	Fail to Reject
	Male	-1.5241	0.12852	Fail to Reject
Age Group	18 to 35	0.1924	0.8493	Fail to Reject
	35 to 50	0.7864	0.42952	Fail to Reject
	50 plus	0.8197	0.41222	Fail to Reject
Race	Caucasian	-3.2215	0.00128	Reject
	Hispanic	3.8732	0.0001	Reject
	African American	-1.5952	0.1096	Fail to Reject
Income	Low	1.8067	0.0703	Fail to Reject
	Moderate	0.7515	0.45326	Fail to Reject
	High	-1.47	0.14156	Fail to Reject

Louisiana Pearl				
	Demographic	Z-score	p-value	Reject/Fail to Reject
Gender	Female	0.4239	0.67448	Fail to Reject
	Male	-1.4204	0.1556	Fail to Reject
Age Group	18 to 35	-0.6428	0.52218	Fail to Reject
	35 to 50	3.0222	0.00252	Reject
	50 plus	0.2969	0.76418	Fail to Reject
Race	Caucasian	2.1632	0.03078	Reject
	Hispanic	-0.3041	0.76418	Fail to Reject
	African American	0.0732	0.9442	Fail to Reject
Income	Low	0.3837	0.70394	Fail to Reject
	Moderate	-0.0137	0.99202	Fail to Reject
	High	0.1834	0.85716	Fail to Reject



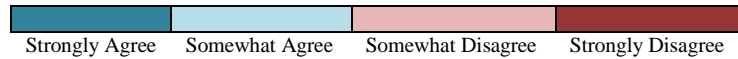
Union Station				
	Demographic	Z-score	p-value	Reject/Fail to Reject
Gender	Female	1.054	0.29372	Fail to Reject
	Male	-0.0216	0.98404	Fail to Reject
Age Group	18 to 35	0.8252	0.40654	Fail to Reject
	35 to 50	4.2156	0	Reject
	50 plus	-1.5947	0.11184	Fail to Reject
Race	Caucasian	-2.3314	0.0198	Reject
	Hispanic	-3.0323	0.00244	Reject
	African American	0.6799	0.4965	Fail to Reject
Income	Low	0.8412	0.4009	Fail to Reject
	Moderate	1.5431	0.12356	Fail to Reject
	High	-1.636	0.101	Fail to Reject

27th and Welton				
	Demographic	Z-score	p-value	Reject/Fail to Reject
Gender	Female	-0.9639	0.33706	Fail to Reject
	Male	1.3484	0.17702	Fail to Reject
Age Group	18 to 35	0.6011	0.5485	Fail to Reject
	35 to 50	1.3468	0.17702	Fail to Reject
	50 plus	1.612	0.1074	Fail to Reject
Race	Caucasian	-0.5875	0.5552	Fail to Reject
	Hispanic	1.4184	0.1556	Fail to Reject
	African American	1.2853	0.19706	Fail to Reject
Income	Low	1.8524	0.06432	Fail to Reject
	Moderate	-0.4247	0.67448	Fail to Reject
	High	-0.3485	0.72634	Fail to Reject

## B.2. Supplementary Heat Map Score Charts Contributing to Final Analysis

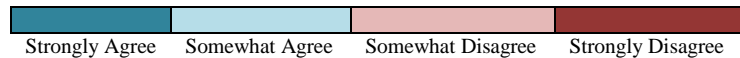
Score Chart of Perceived Space Closed-Ended Survey Questions, based on Median Ranked Response

	Walking Ease	Safe from Traffic	Safe from Crime	Neighborhood is Great for Walking	Walking is Fastest Mode
Alameda	Somewhat Agree	Somewhat Agree	Somewhat Agree	Somewhat Agree	Somewhat Agree
Louisiana Pearl	Strongly Agree	Somewhat Agree	Strongly Agree	Strongly Agree	Somewhat Agree
Union Station	Strongly Agree	Somewhat Agree	Somewhat Agree	Somewhat Agree	Somewhat Agree
27 <sup>th</sup> and Welton	Strongly Agree	Somewhat Agree	Somewhat Agree	Somewhat Agree	Somewhat Agree



Score Chart of 3D Walk Score Ranking

	3D Score	Population Density	Land Use Entropy	Intersection Number
Alameda	-2.39	323.4	0.583	66
Louisiana Pearl	0.23	874.8	0.605	106
Union Station	-1.16	839.6	0.508	87
Welton	3.32	1502.4	0.713	137

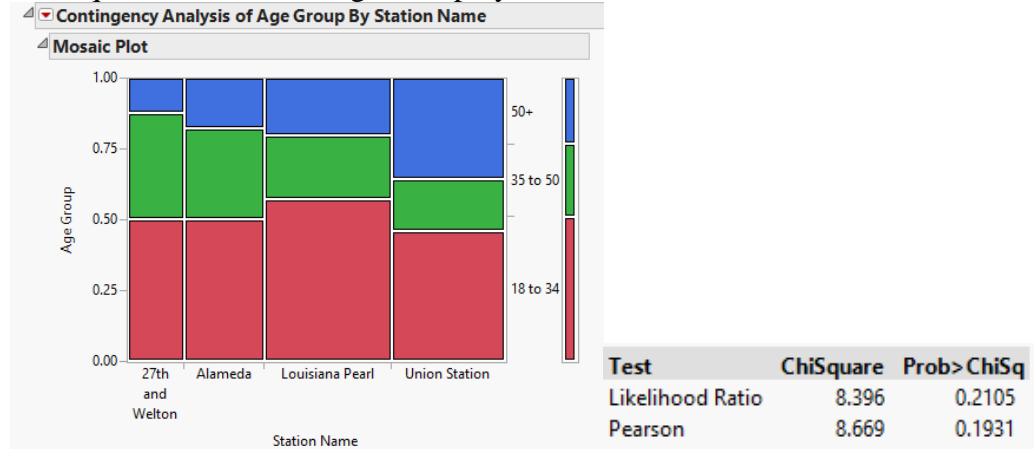


Score Chart of Perceived Space Open-Ended Questions about Overall Perceptions, based on Proportions

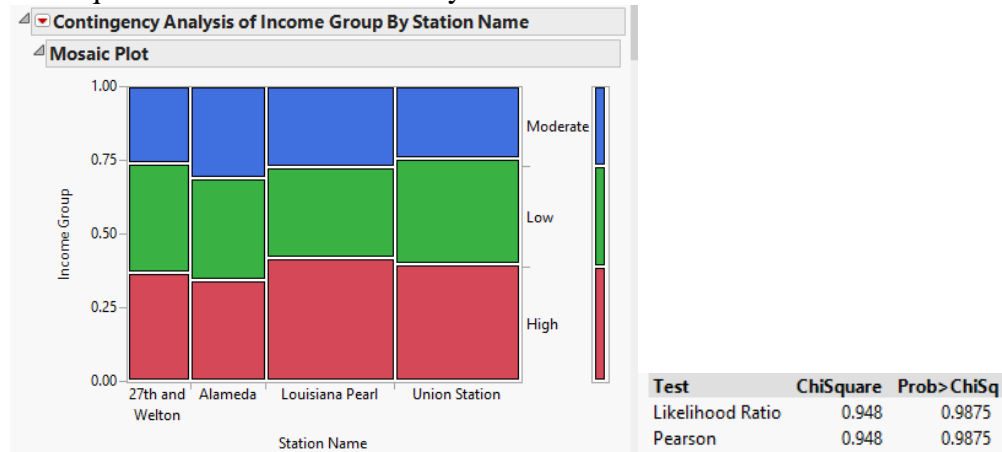
	Good	Acceptable	Bad
Alameda	0.39	0.39	0.22
Louisiana Pearl	0.77	0.16	n/a
Union Station	0.61	0.39	0.04
27 <sup>th</sup> and Welton	0.37	0.50	0.23

### B.3. Pearson's Chi-Squared Test Results for Station Demographic Differences

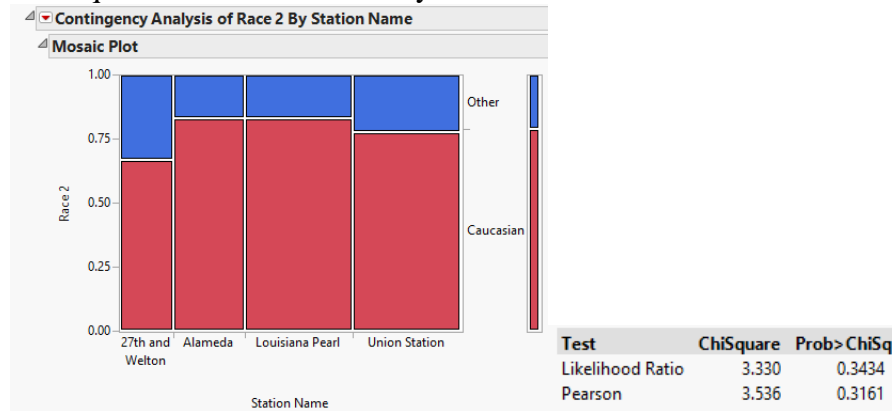
#### Chi-Squared Results for Age Group by Station



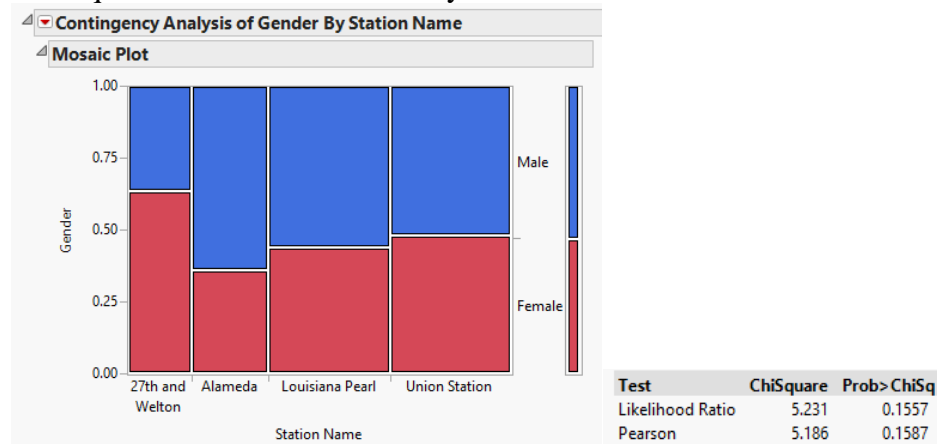
#### Chi-Squared Results for Income by Station



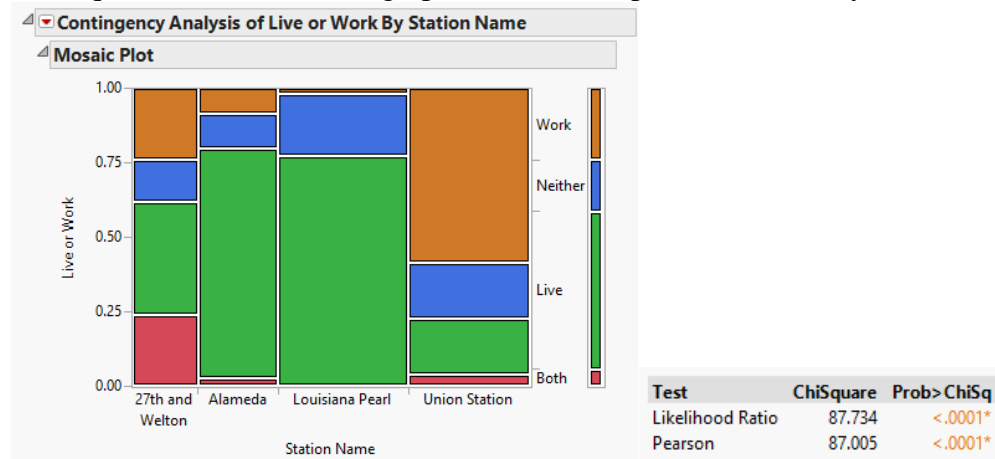
#### Chi-Squared Results for Race by Station



## Chi-Squared Results for Gender by Station

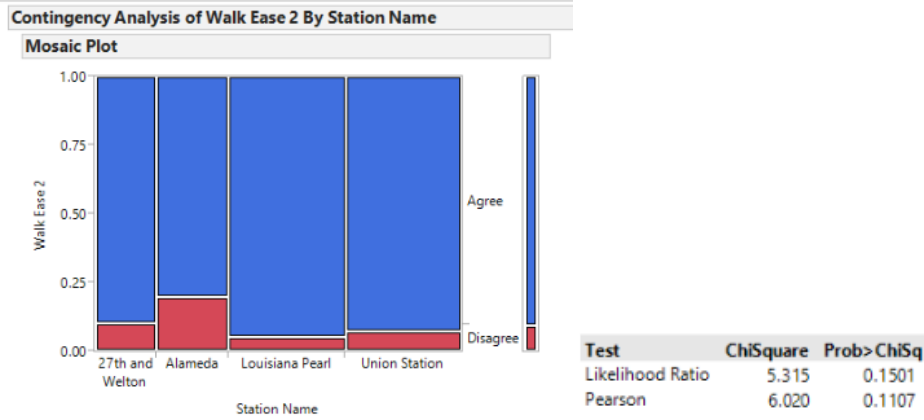


## Chi-Squared Results for Geographic Relationship to the Station by Station

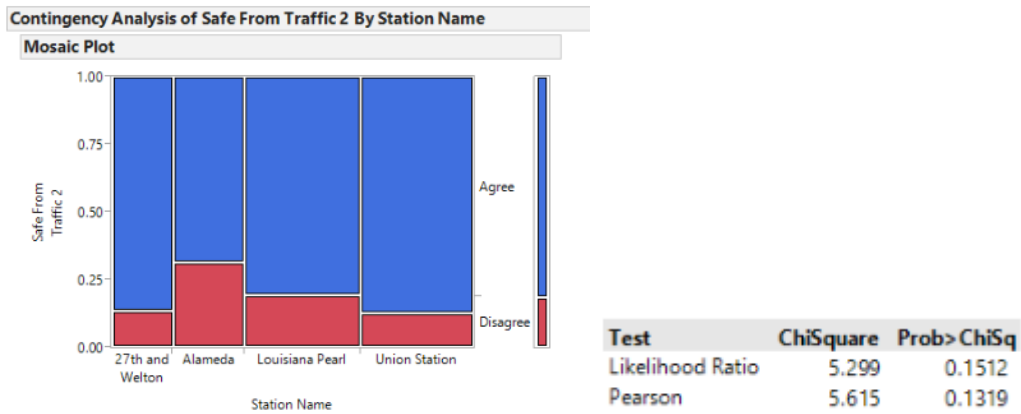


## B.4. Pearson's Chi-Squared Test Results for Station Closed Question Perception Differences

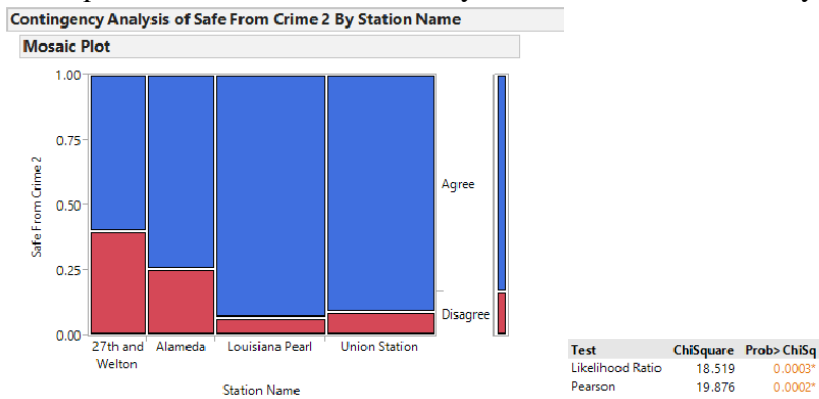
Chi-Squared Results for "I am Capable of Walking with Ease" by Station



Chi-Squared Results for "I Generally Feel Safe from Traffic" by Station

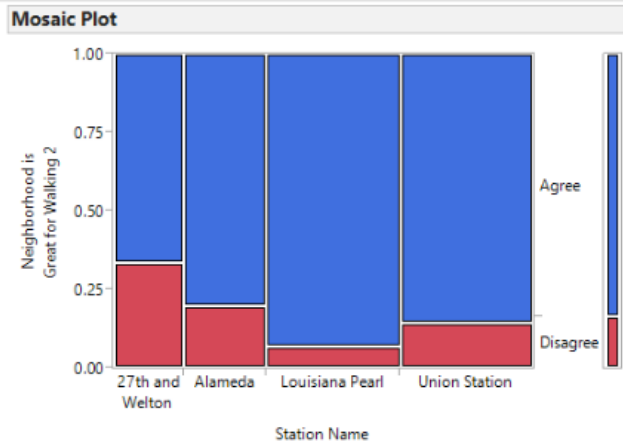


Chi-Squared Results for "I Generally Feel Safe from Crime" by Station



## Chi-Squared Results for “I Think the Neighborhood is Great for Walking” by Station

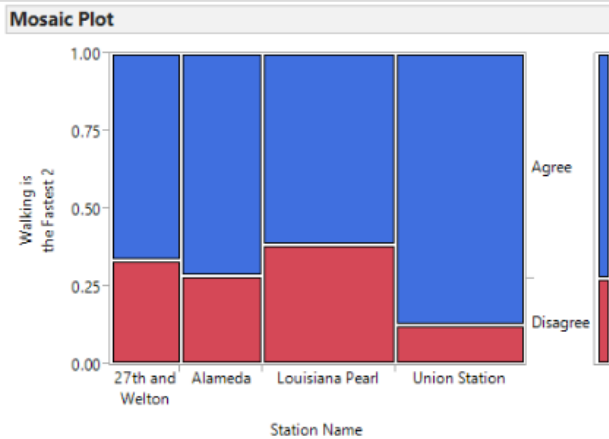
Contingency Analysis of Neighborhood is Great for Walking 2 By Station Name



Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	10.117	0.0176*
Pearson	10.501	0.0148*

## Chi-Squared Results for “I Think that Walking is the Fastest Way to Get around This Area” by Station

Contingency Analysis of Walking is the Fastest 2 By Station Name

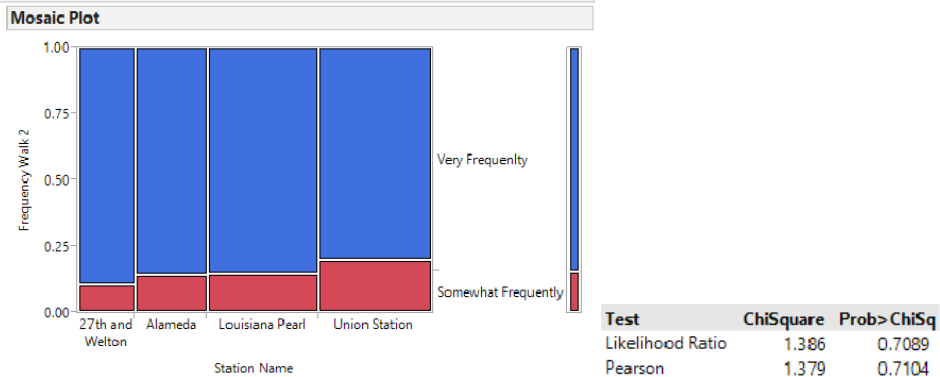


Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	10.813	0.0128*
Pearson	10.028	0.0183*

## B.5. Pearson's Chi-Squared Test Results for Station Closed Question Behavior Differences

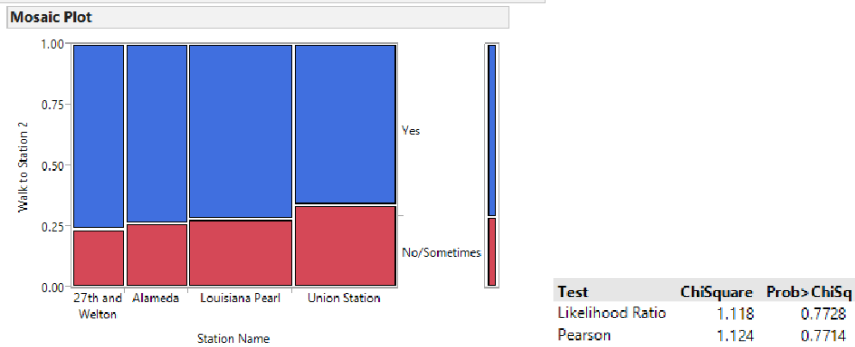
Chi-Squared Results for "Frequency of Walking in the Neighborhood" by Station

Contingency Analysis of Frequency Walk 2 By Station Name



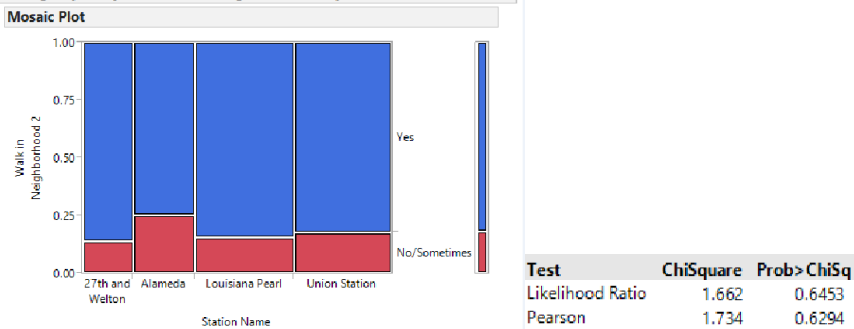
Chi-Squared Results for "I Normally Walk to the Station" by Station

Contingency Analysis of Walk to Station 2 By Station Name



Chi-Squared Results for "I Normally Walk in the Neighborhood" by Station

Contingency Analysis of Walk in Neighborhood 2 By Station Name



## B.6. Sign Test Results for Significant Demographic Differences in Composite Sketch Distributions

### GOOD AREAS

#### Welton—Caucasian

Sign Test	
Welton_NonCaucasian- Welton_Caucasian	
Test Statistic M	-42.500
Prob ≥  M	<.0001*
Prob ≥ M	1.0000
Prob ≤ M	<.0001*

#### Welton—Income

Sign Test			
	Welton_mod- Welton_low	Welton_high- Welton_low	Welton_high- Welton_mod
Test Statistic M	6.000	25.000	22.500
Prob ≥  M	0.1409	<.0001*	<.0001*
Prob ≥ M	0.0704	<.0001*	<.0001*
Prob ≤ M	0.9593	1.0000	1.0000

#### Welton—Age Group

Sign Test			
	Welton_36to50- WeltonAge_18to35	Welton_51plus- WeltonAge_18to35	Welton_51plus- Welton_36to50
Test Statistic M	28.000	-41.500	-48.000
Prob ≥  M	<.0001*	<.0001*	<.0001*
Prob ≥ M	<.0001*	1.0000	1.0000
Prob ≤ M	1.0000	<.0001*	<.0001*

#### Welton—Gender

Sign Test	
Welton_Female- Welton_Male	
Test Statistic M	-19.500
Prob ≥  M	0.0003*
Prob ≥ M	0.9999
Prob ≤ M	0.0001*



## BAD AREAS

### Welton—Race

Sign Test	
Welton_NonCaucasian- Welton_Caucasian	
Test Statistic M	-0.500
Prob $\geq  M $	1.0000
Prob $\geq M$	0.5937
Prob $\leq M$	0.5000

### Welton—Income

Sign Test			
Welton_mod- Welton_low    Welton_high- Welton_low    Welton_high- Welton_mod			
Test Statistic M	52.500	7.500	-55.500
Prob $\geq  M $	<.0001*	0.0201*	<.0001*
Prob $\geq M$	<.0001*	0.0100*	1.0000
Prob $\leq M$	1.0000	0.9962	<.0001*

### Welton—Age

Sign Test			
Welton_36to50- WeltonAge_18to35    Welton_51plus- WeltonAge_18to35    Welton_51plus- Welton_36to50			
Test Statistic M	-31.500	-31.500	-0.500
Prob $\geq  M $	<.0001*	<.0001*	1.0000
Prob $\geq M$	1.0000	1.0000	1.0000
Prob $\leq M$	<.0001*	<.0001*	0.5000

### Welton—Gender

Sign Test	
Welton_Female- Welton_Male	
Test Statistic M	47.500
Prob $\geq  M $	<.0001*
Prob $\geq M$	<.0001*
Prob $\leq M$	1.0000

#### Alameda—Age

Sign Test			
	Alameda_36to50- Alameda_18to35	Alameda_51plus- Alameda_18to35	Alameda_51plus- Alameda_36to50
Test Statistic M	-42.000	-53.000	-25.500
Prob ≥  M	<.0001*	<.0001*	<.0001*
Prob ≥ M	1.0000	1.0000	1.0000
Prob ≤ M	<.0001*	<.0001*	<.0001*

#### Union—Caucasian

Sign Test	
	Union_NonCaucasian- Union_Caucasian
Test Statistic M	-24.500
Prob ≥  M	<.0001*
Prob ≥ M	1.0000
Prob ≤ M	<.0001*

#### Union—Income

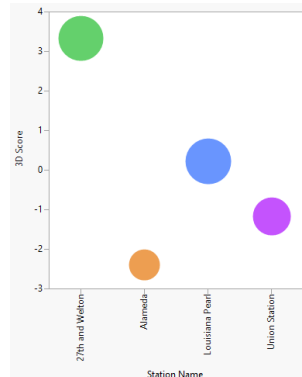
Sign Test			
	Union_mod- Union_Low	Union_High- Union_Low	Union_High- Union_mod
Test Statistic M	-16.000	-13.500	13.500
Prob ≥  M	0.0001*	0.0028*	0.0013*
Prob ≥ M	1.0000	0.9994	0.0007*
Prob ≤ M	<.0001*	0.0014*	0.9997

#### Louisiana Pearl—Race

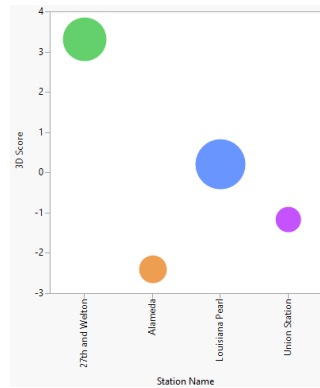
Sign Test	
	Louisiana_NonCaucasian- Louisiana_Caucasian
Test Statistic M	-19.000
Prob ≥  M	<.0001*
Prob ≥ M	1.0000
Prob ≤ M	<.0001*

## B.9. Bubble Plots of the Three Spatial Measures of Walkability

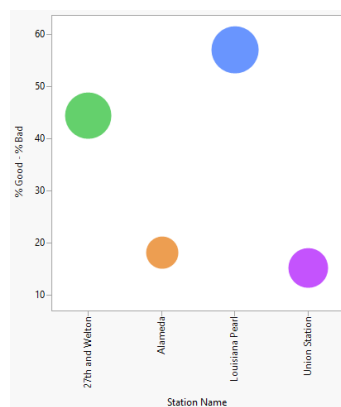
Bubble Plots of General Measures Sized by Distance-Oriented



Bubble Plots of General Measures Sized by Perceived

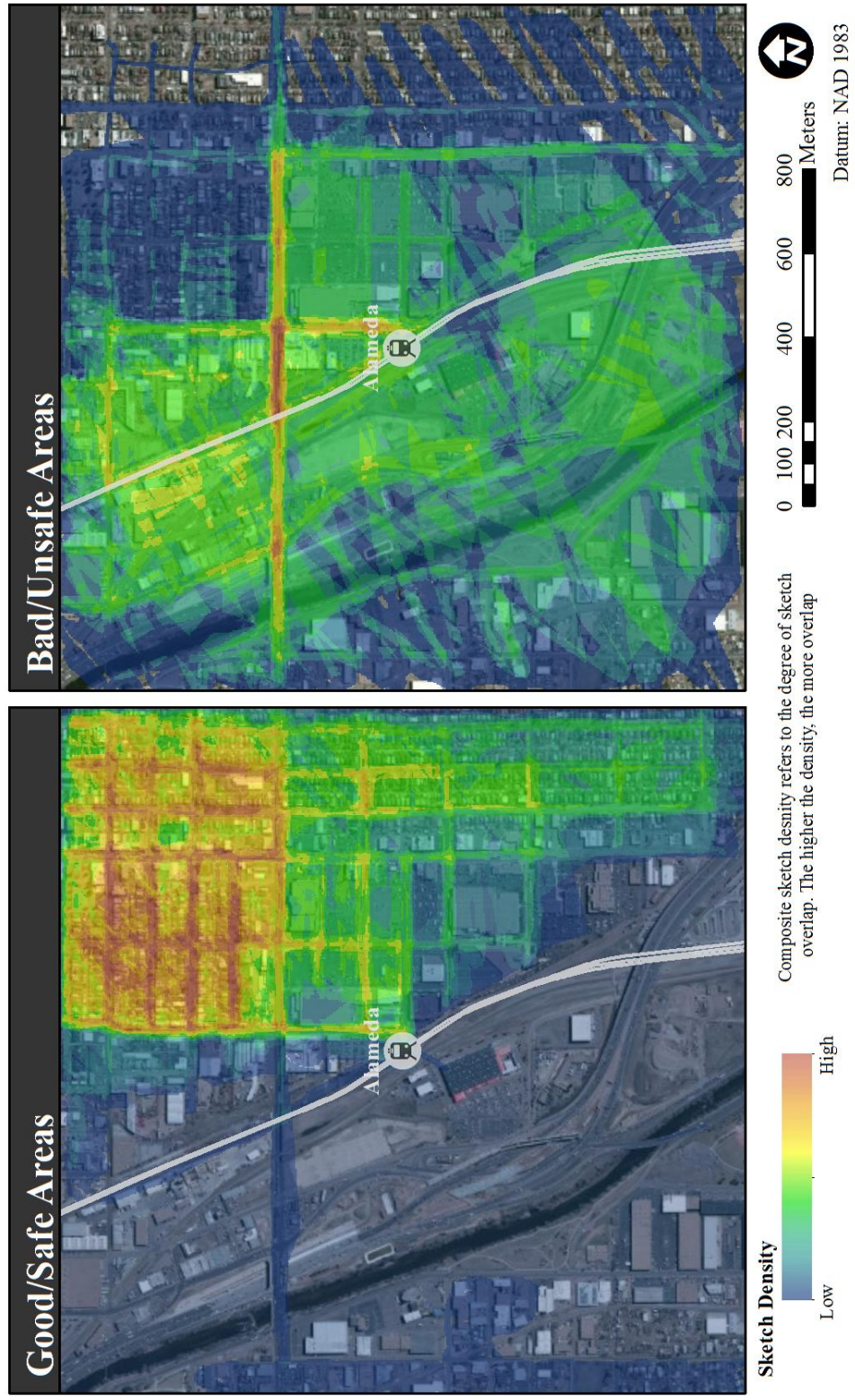


Bubble Plots of Perceived Space, Sized by Distance-Oriented



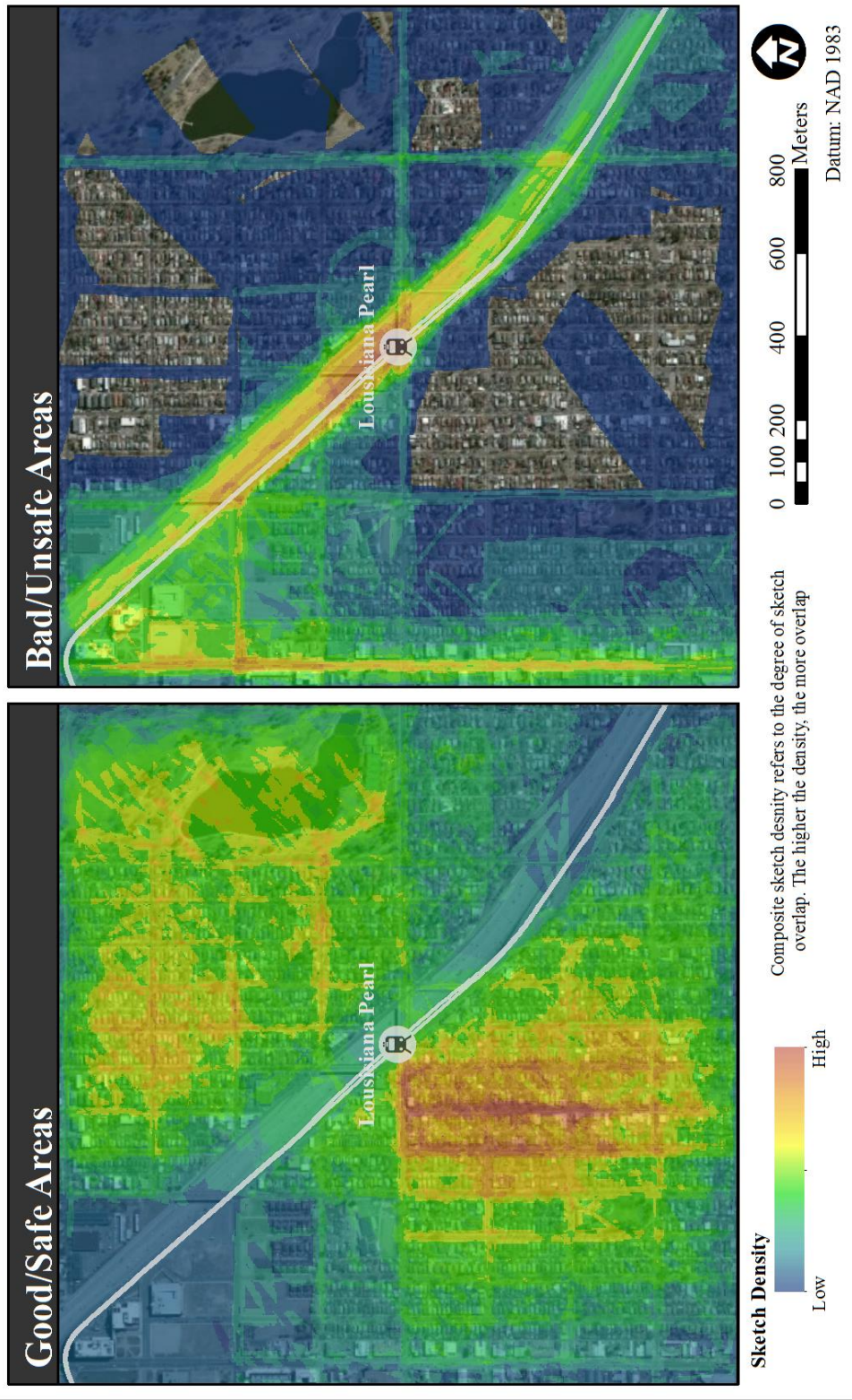
## **Appendix D: Composite Sketch Maps**

## Perceptions of Space: Composite Sketch Maps, Alameda

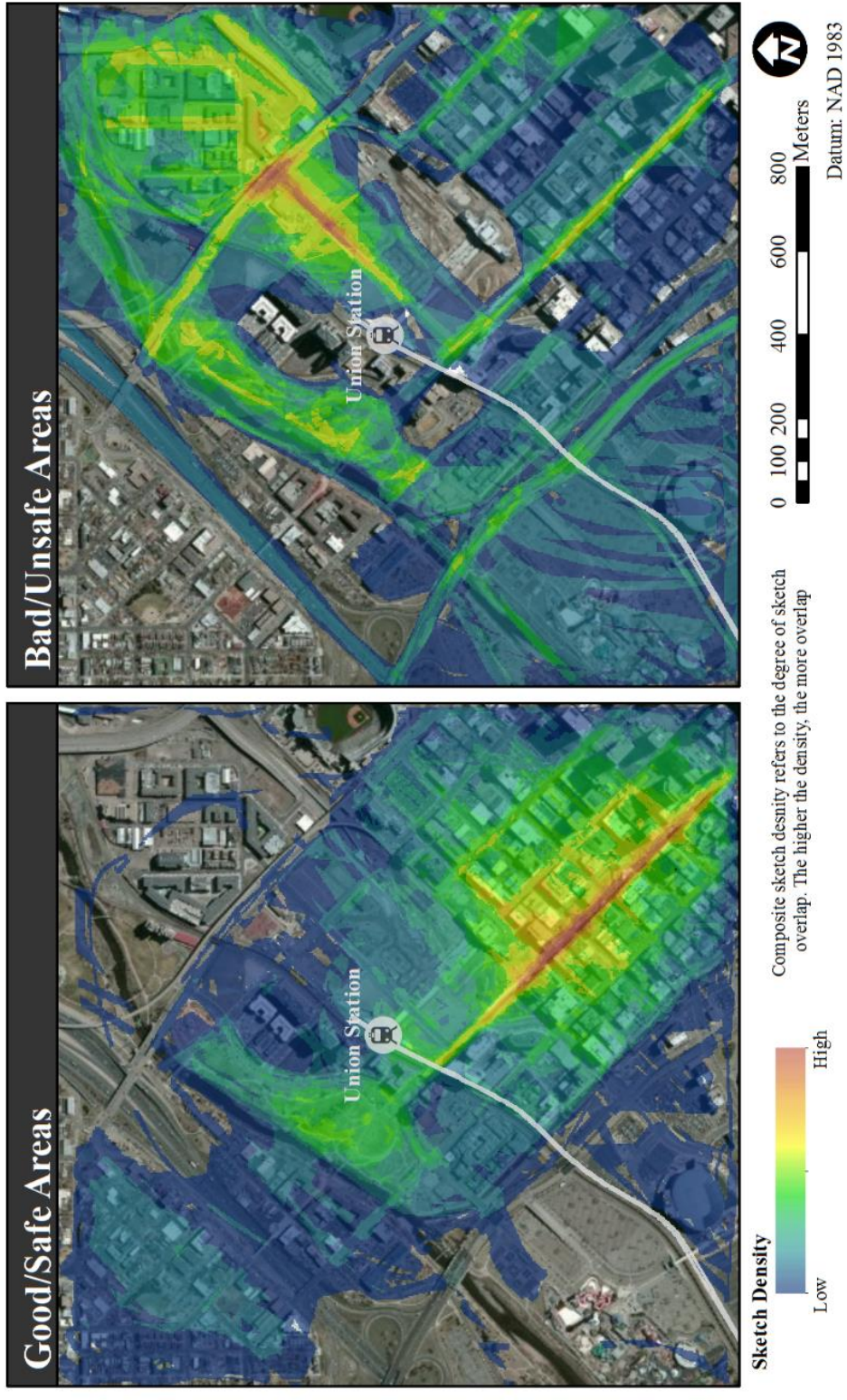




# Perceptions of Space: Composite Sketch Maps, Louisiana Pearl

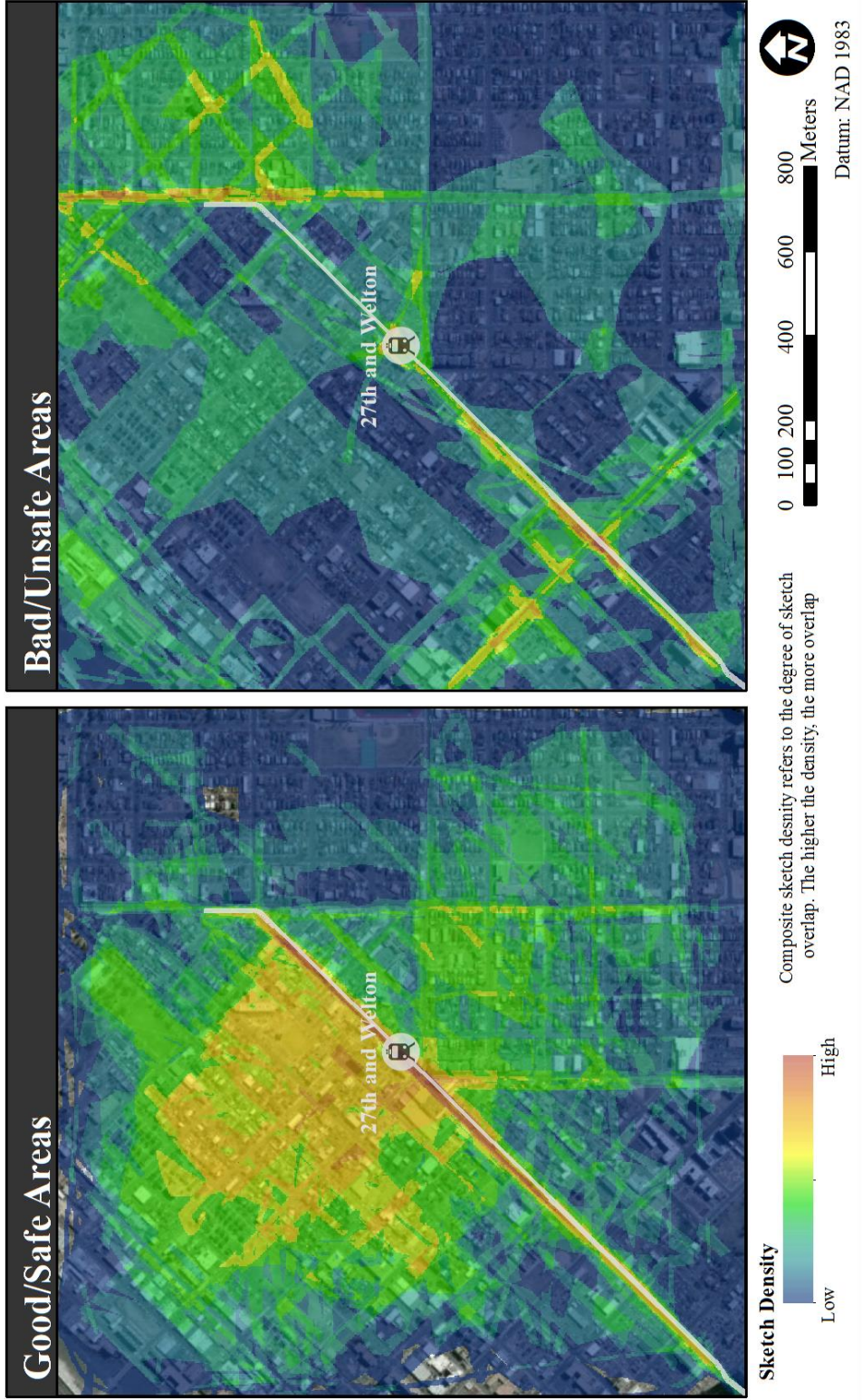


# **Perceptions of Space: Composite Sketch Maps, Union Station**



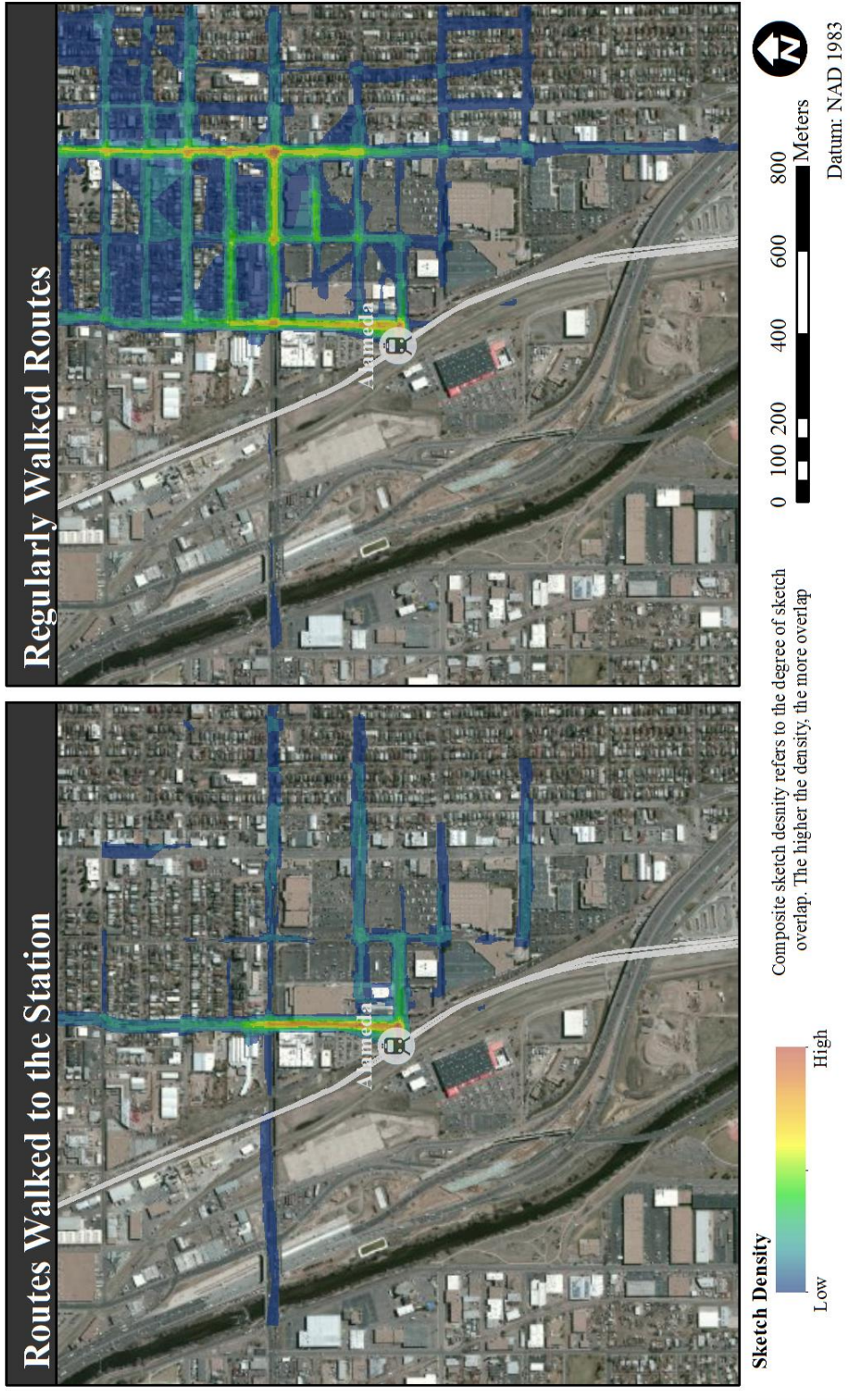


# Perceptions of Space: Composite Sketch Maps, 27th and Welton





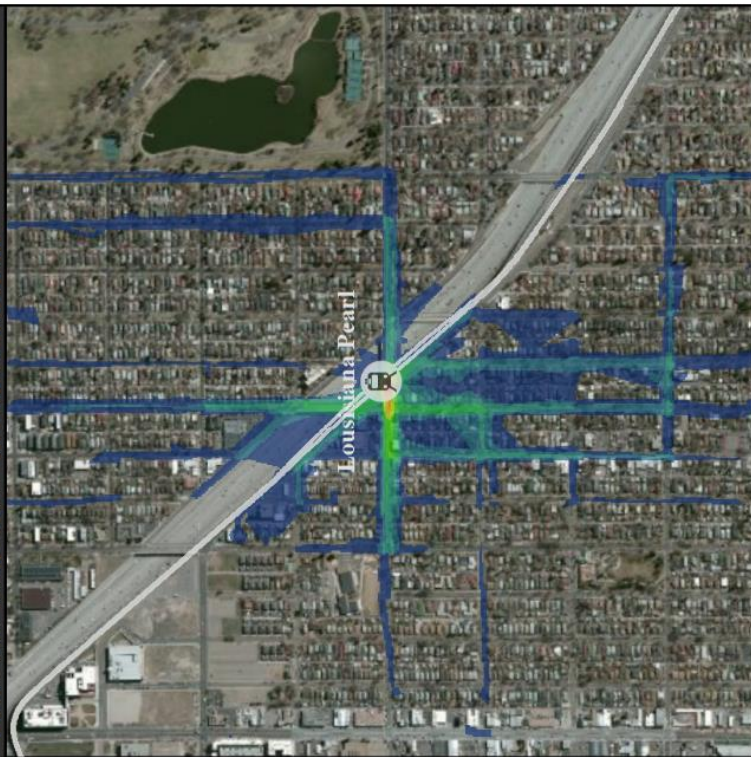
# Walking Behavior: Composite Sketch Maps, Alameda





# Walking Behavior: Composite Sketch Maps, Louisiana Pearl

Routes Walked to the Station

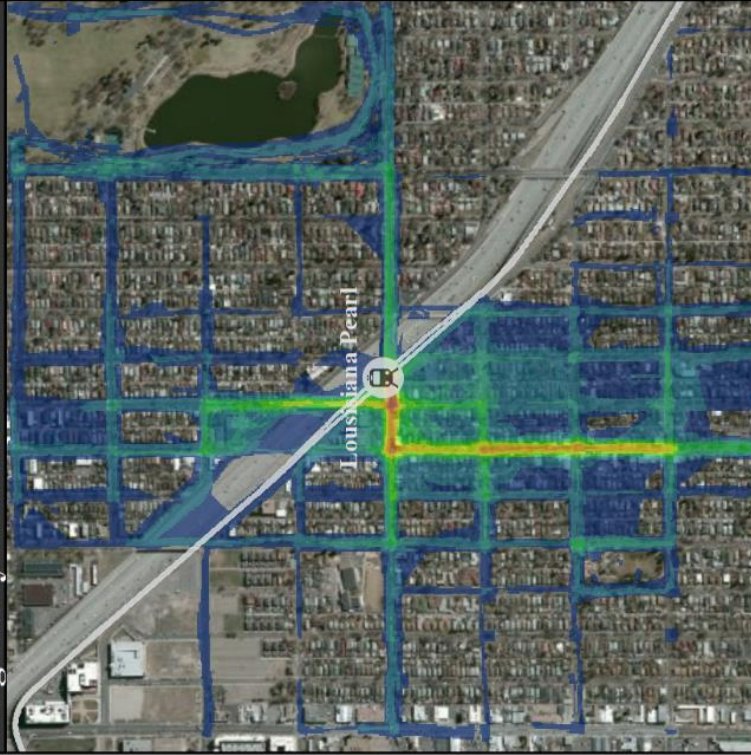


**Sketch Density**

Low High

Composite sketch density refers to the degree of sketch overlap. The higher the density, the more overlap

Regularly Walked Routes

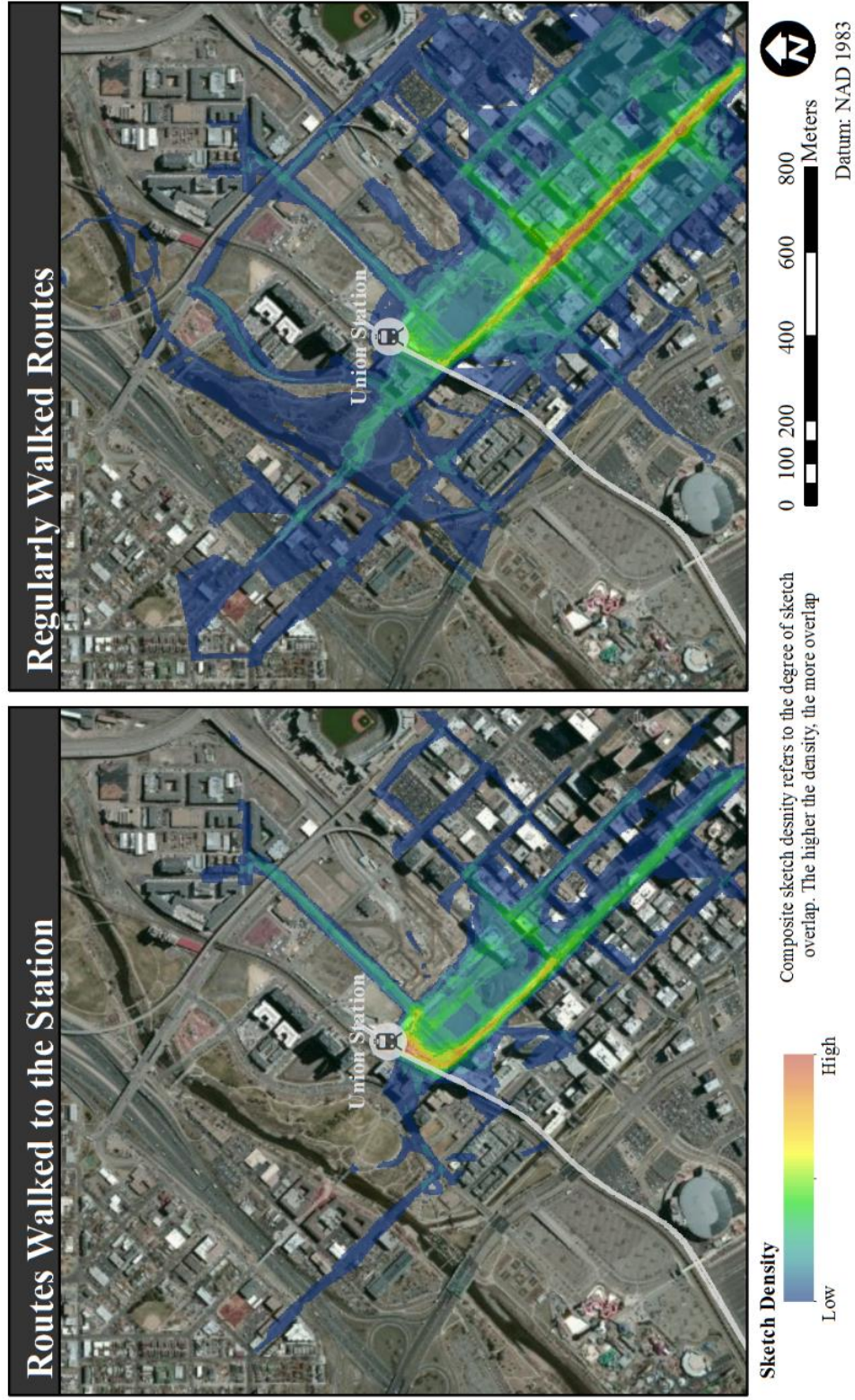


0 100 200 400 600 800 Meters

Datum: NAD 1983

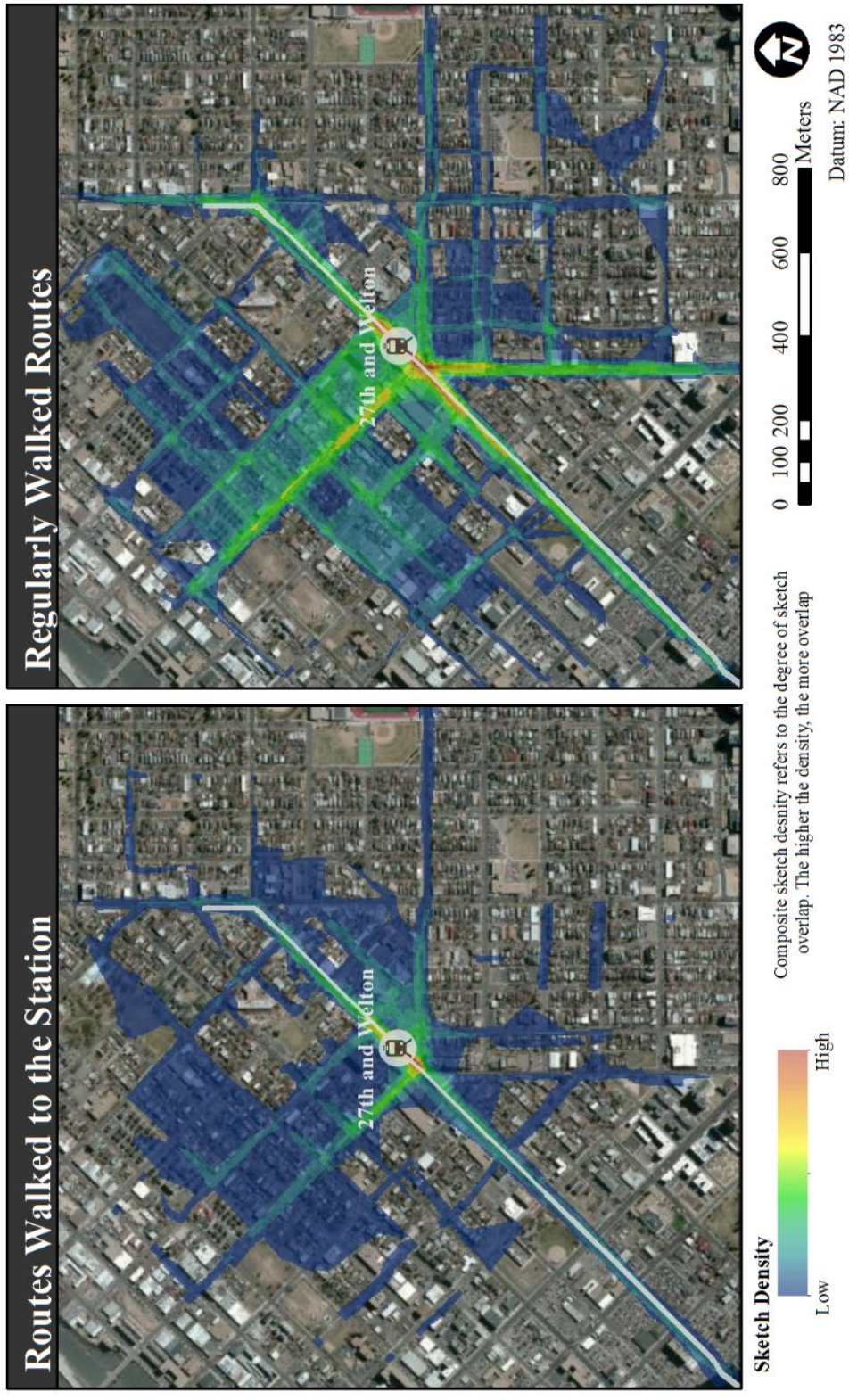


## Walking Behavior: Composite Sketch Maps, Union Station





# Walking Behavior: Composite Sketch Maps, 27th and Welton





# Walking Behavior: Composite Sketch Maps, Alameda

Routes Walked to the Station



Regularly Walked Routes



Sketch Density  
Low High



Half Mile Walkshed

0 100 200 400 600 800 Meters  
Datum: NAD 1983

# **Walking Behavior: Composite Sketch Maps, Louisiana Pearl**

**Routes Walked to the Station**

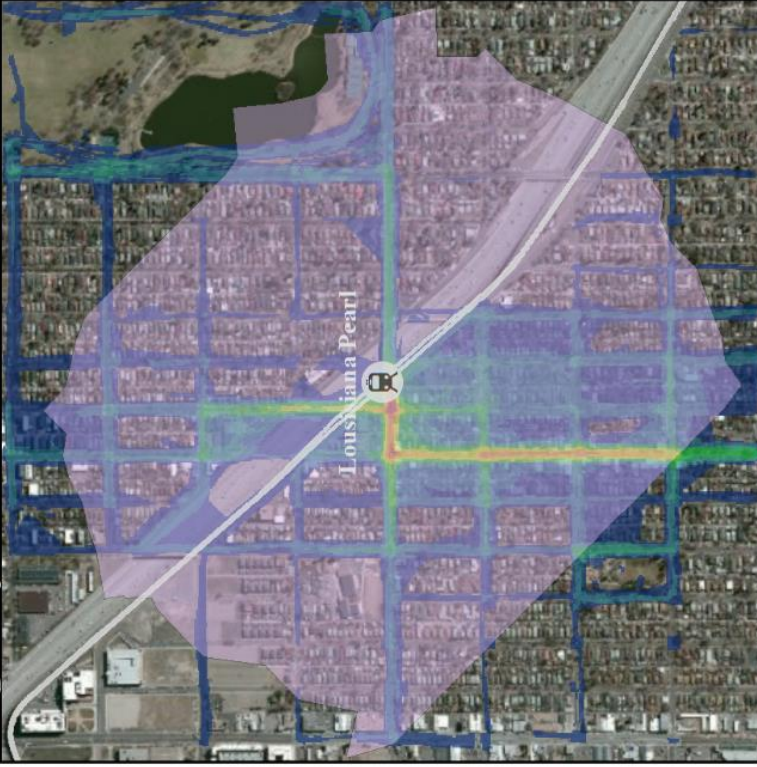


**Sketch Density**

Low High

Half Mile Walkshed

**Regularly Walked Routes**



0 100 200 400 600 800 Meters

Datum: NAD 1983

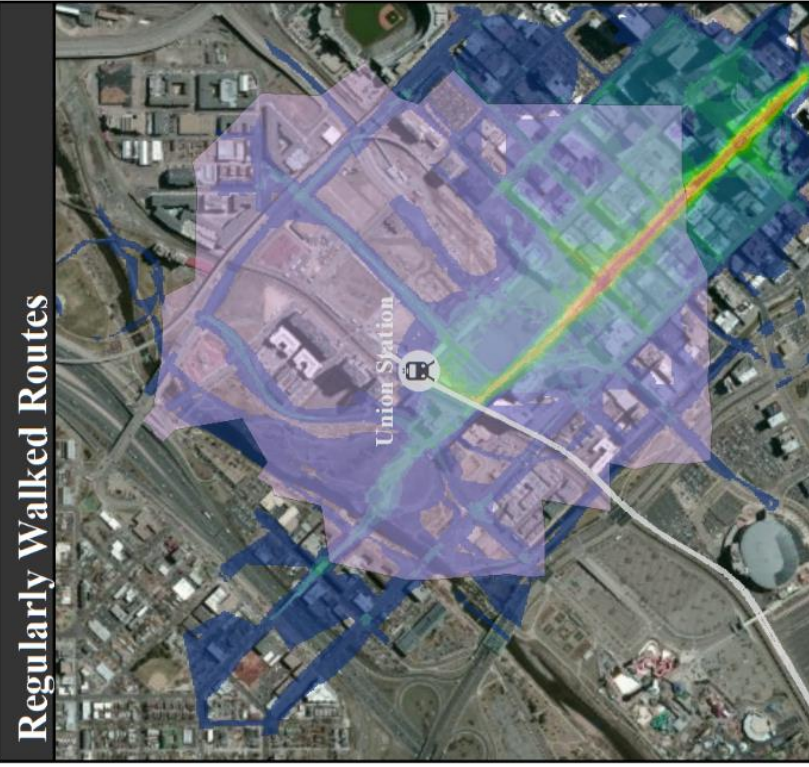


# Walking Behavior: Composite Sketch Maps, Union Station

Routes Walked to the Station



Regularly Walked Routes



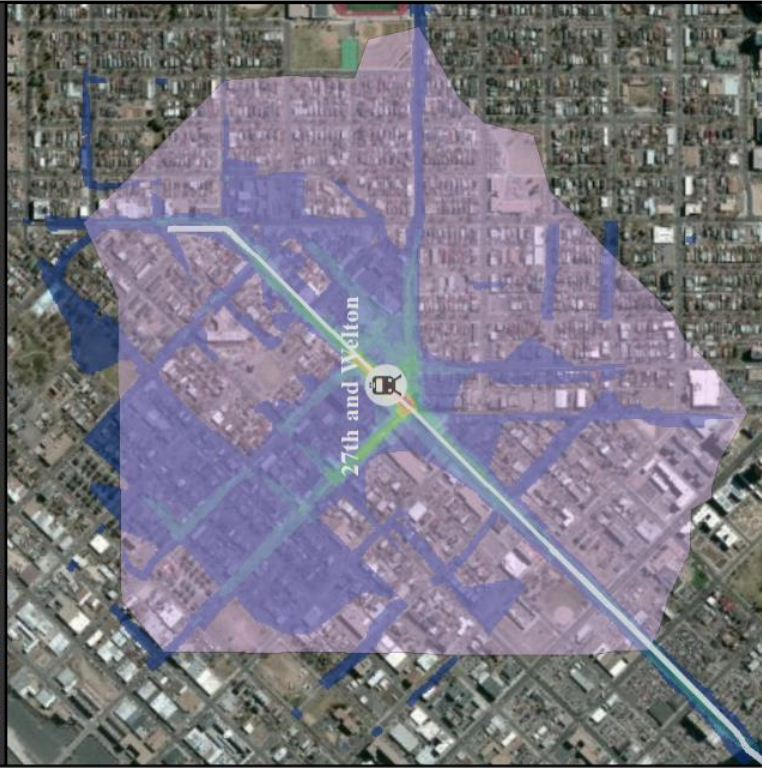
Sketch Density  
Low High

0 100 200 400 600 800 Meters  
Datum: NAD 1983



# **Walking Behavior: Composite Sketch Maps, 27th and Welton**

**Routes Walked to the Station**



**Sketch Density**

Low High

Half Mile Walkshed

**Regularly Walked Routes**



0 100 200 400 600 800 Meters

Datum: NAD 1983